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THE

AËRONAUTICAL JOURNAL.

A Monthly Illustrated Magazine devoted to all subjects connected with the Navigation of the Air.

EDITED FOR THE

COUNCIL OF THE ROYAL AËRONAUTICAL SOCIETY

BY

J. LAURENCE PRITCHARD, Fellow.

VOL. XXV.

1921.

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(FOUNDED 1897 in succession to the ANNUAL REPORTS).

THE ORGAN OF THE ROYAL AËRONAUTICAL SOCIETY.

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Edited for the Council by J. LAURENCE PRITCHARD, Associate Fellow.

All communications should be addressed to the Editor.

No. 121. JANUARY, 1921. VOL. XXV.

Notices of the Royal Aëronautical Society.

Visit to National Physical Laboratory.

As announced in a special notice which is being circulated to every member, arrangements have been made for a party of members to be shown the work of the Aerodynamic Department of the National Physical Laboratory, Teddington, on Wednesday afternoon, January 26th. Any member who wishes to take advantage of this opportunity should send in his name to the Secretary on or before January 17th *at the latest.*

It is proposed to travel by the 1.56 p.m. train from Waterloo (arriving at Teddington at 2.31 p.m.), and return by the 4.43 or 5.3 p.m. train from Teddington (arriving at Waterloo at 5.9 and 5.39).

Members of the party should obtain their own railway tickets and meet at the Laboratory, which is about five minutes' walk from Teddington Station.

Transactions.

A new volume in the "Transactions of the Royal Aeronautical Society" has just been published and may be obtained at the Society's offices, price 5s. It embodies a paper on "Aero-Engine Efficiencies," by Dr. A. H. Gibson, of Manchester University, which contains a large amount of important experimental data on the thermal efficiency of internal combustion engines.

Air Ministry Load Factor Committee.

At the request of the Air Council, Lieutenant-Colonel M. O'Gorman, C.B., and Captain Geoffrey de Havilland, O.B.E., A.F.C., have been nominated to represent the Society on the reconstituted Air Ministry Load Factor Committee.

Scottish Branch.

The members of the Scottish Branch, through the courtesy of Sir William Beardmore, Ltd., recently visited this firm's works at Inchinnan, when they were given an opportunity of examining the new rigid airship "R.36" which is in process of construction for the Government.

At a meeting held on December 18th it was decided to inaugurate a Students' Section, under the title of the Glasgow University Ex-Airmen and Students' Discussion Society, in order to provide opportunities for informal discussions.

The following have been elected to the Scottish Branch in the various grades as shown:—*Members:* Capt. W. G. Cleghorn, Professor A. L. Mellanby, N. A. Yarrow. *Associate Members:* M. E. Denny, R. J. Findlay, T. Howard Rudd, A. Speedie, J. Tweedie, Capt. C. E. Ward.

Donations.

The Council desire gratefully to acknowledge the gift of "Rigging, the Erection and Trueing-up of Aeroplanes," by F. W. Halliwell, the author, and also the gift of lantern slides from the Bristol Aeroplane Company.

Binding Cases for the Journal.

Arrangements have been made for the binding of complete sets of the Journal for 1920 in blue cloth cases with gilt lettering at a charge of 4s. 6d. per volume, including the supply of the case. Members who desire to take advantage of this arrangement should forward their sets direct to The Lewes Press, Ltd., High Street, Lewes, at the same time sending a remittance for 4s. 6d. to the Secretary at the Society's offices. A note stating the name and address of the sender should be included in the parcel to the binders. The complete volumes will be returned direct to members postage paid.

Individual sets of former volumes can be bound in the same style at a price of 5s. 6d. per volume, including supply of binding case.

Library.

The following books have been received and placed in the Society's Library:—"Rigging, the Erection and Trueing-up of Aeroplanes," by F. W. Halliwell; "The Airplane," by Frederick Bedell; "Practical Aeroplane Construction," by by F. T. Hill, A.F.R.Aë.S.; "Jane's All the World's Aircraft, 1920"; "Soaring Flight," by Lieut.-Col. R. de Villamil; "Report of the Lubricants and Lubrication Inquiry Committee"; "Smithsonian Physical Tables," prepared by Frederick E. Fowle.

Lectures.

The following lectures will take place during the remainder of the present session. It will be noticed that the time of starting varies on different dates. This has been rendered necessary to fit in with other engagements of the Theatre of the Royal Society of Arts:—

January 20th, 5.0 p.m.—Lord Montagu of Beaulieu, "The Cost of Air Ton-Miles compared with other forms of Transport."

February 3rd, 5.30 p.m.—Major G. Dobson, "Meteorology." Wing Commander Outram, C.B.E., "Ground Engineering."

February 17th, 5.30 p.m.—Mr. F. Handley Page, "The Handley Page Wing."

March 3rd, 5.0 p.m.—Mr. J. W. W. Dyer, "Airship Fabrics." Major T. Orde Lees, "Parachutes."

March 17th, 5.30 p.m.—Captain D. Nicolson, "Flying Boat Construction."

Juvenile Lecture.

Air Commodore E. M. Maitland, C.M.G., D.S.O., A.F.C., has consented to give the annual Juvenile Lecture at 3 p.m. on the afternoon of Tuesday, January 11th, at the Royal Society of Arts, John Street, Adelphi, on "Airship Flights of Fact and Fancy," which will be very fully illustrated with lantern slides. Tickets for the children of members and their friends may be obtained from the Secretary.

Committees.

The usual monthly meetings will take place on January 18th as follows:—Lectures and Publications Committee, 4.0 p.m.; Candidates Qualifications Committee, 4.30 p.m.; Council, 5.0 p.m.

New Members.

Members are asked to note that, commencing with the present issue, the last three advertisement pages of the Journal contain an announcement of the objects, terms of membership, etc., of the Society, and a list of publications. It is felt that this may be useful for the purpose of introducing new members. Copies of these pages, printed separately as leaflets, may be obtained on application to the Secretary.

W. Lockwood Marsh, *Secretary.*

PROCEEDINGS.

FOURTH MEETING, FIFTY-SIXTH SESSION.

The Fourth Meeting of the Fifty-Sixth Session was held in the Hall of the Royal Society of Arts on Thursday, November 18th, 1920, Air Vice-Marshal Sir Edward Ellington occupying the Chair.

The Chairman said it was his pleasure to introduce Mons. Louis Damblanc, who had come from France to give them a lecture on Helicopters. He was sure the Members would agree that he was doubly welcome, first as a member of the French nation, our Allies, and secondly as a thoughtful and original experimenter in one aspect of aviation. He was an engineer of scientific training, who since 1917 had been closely connected, on behalf of the French Government, with inventions and technical experiments. The French War Office, he understood, had recently given him an order to make a helicopter to his design and test it out. Besides being a scientific investigator, he had proved himself a courageous pioneer in practical aviation experiments, and the Members would be sorry to hear he recently had an accident in the course of his preliminary experiments on helicopters. He had some diffidence about reading a lecture in a foreign language, and therefore Capt. Sayers would read the greater part of it.

Mons. Damblanc (with Capt. W. H. Sayers as his deputy during the latter part) then delivered the following Lecture :—

THE PROBLEM OF THE HELICOPTER.

It is a very great honour to me to have to speak this evening before this learned assembly, and I have to thank you very sincerely for the occasion which you have offered me of discussing before you a very important question, one which is of interest to the whole of the aeronautical world, namely, the problem of the helicopter.

My aim will be but modest, for I shall simply attempt to develop those essential arguments which have given me such entire confidence in the practicability of this type of heavier-than-air machine, and I shall be content if at the end of this paper I have been able, not to convince you, but at least to interest you in the cause which I have at heart.

The helicopter is not a competitor of the aeroplane. It is an entirely different type of aircraft, but the one is the complement of the other, and if their respective uses are not the same, they nevertheless will be of equal importance in that immense future which we all believe to be reserved for aircraft.

For military purposes the helicopter will be an incomparable observation machine, and, when its horizontal speed becomes equal to that of an aeroplane, a formidable bombing machine. For work at sea its advantages are evident. Aeroplanes cannot land on the decks of warships except in the face of great difficulties and with the aid of special and encumbering landing decks, which involve a waste of space which can scarcely be tolerated.

The helicopter alone is capable of getting over these difficulties in a satisfactory manner. By its use it will be possible to rise vertically from the deck of a ship and to land in the same way. Merely to mention these several applications is to justify the interest which has been taken in the attempts to develop this type of machine.

I will not waste time in discussing the history of the helicopter. All the world knows that for more than a century many inventors in England as in France have taken intense interest in this problem. The greater number of them have stopped short at the production of children's toys, using for motive power, either bent whale-bone, skeins of rubber or steel springs.

One has only to read the numerous patent specifications which have been taken out concerning helicopters to realise that most of the authors have had either the most elementary or the most fantastic ideas.

The majority of the patentees have considered only the vertical ascent of the machine, and have concerned themselves neither with the maintenance in the air nor the gliding descent of the machine. Such conceptions will not stand examination.

In order to be practicable, any kind of flying machine must give complete guarantees of stability under all circumstances of flight.

It was in 1903 that the late Col. Renard, in a very striking communication to the Académie des Sciences, brought the first gleam of light to bear upon the conditions of vertical flight. This scientist with sure intuition, with enlightening and fertile reasoning, has established the fundamental laws which still rule in all practical inquiries into the behaviour of lifting airscrews. I propose to speak of his works and I shall divide my study of them into three chapters :—

(1) Lifting force and lifting airscrews;
(2) Construction of helicopters; and
(3) The gliding descent of a helicopter with stopped engine.

(1) LIFTING FORCE AND LIFTING SCREWS.

Col. Charles Renard, in three communications to the Académie des Sciences, has dealt completely with the question of lifting airscrews. I will recall to you the title of his celebrated notes.

The first (November 23, 1903) was entitled "Upon the Possibility of Sustaining in the Air a Machine of the Helicopter Type, using Internal Combustion Engines in their present state of Lightness."

The second (December 7, 1903) bore the title "Upon the Qualities of Lifting Airscrews," and finally the third, presented several months before his death at Chalais-Meudon (where during twenty-seven years he had unceasingly pursued his scientific researches) was entitled "A New Method of Construction for Airscrews."

With the aid of aerodynamic balances, Col. Renard had spent eighteen years in studying completely the functioning of lifting airscrews, working with no translational motion, and he had determined the characteristic equations of their operation. The fundamental formulæ arrived at by Col. Renard are the following:

Thrust in Kg. $= F = \alpha n^2 D^4$.

Power expended in H.P. $= T = \beta n^3 D^5$.

Where n = revolutions per second, D = diameter of the screw in metres, and α and β are constants for any member of a family of similar airscrews.

The expression for the useful thrust per horse power absorbed is given by

$$F/T = \alpha/\beta D \times 1/n.$$

It can be seen at once that for the same airscrew the thrust per unit of power is greater and greater as the speed of revolution becomes smaller.

Sustentative Value (Qualité Sustentative).

Col. Renard has given this name to a characteristic figure used in the study of an airscrew, which is determined in the following manner :—

For an airscrew of diameter D the area of the circle swept out by the blades will be :—$S = \eta D^2/4$.

If we call S' the area of an imaginary plane which dropping vertically at a speed, V' will produce the same thrust F as that given by the airscrew for the same power expended = T, then the "qualité" or sustentative value defined by Renard is $q = S'/S$.

It can be seen at once that S' increases with the "qualité" of the airscrew. In order to obtain given thrust F, the greater the equivalent plane is the less is the work expended in order to obtain this given thrust. This simple statement proves that augmentation of the "qualité" is equivalent to increasing the aerodynamic efficiency of the airscrew in question.

If K is the normal resistance coefficient of air one has in the case of the equivalent plane

$$F = KS'V'^2 \text{ and } T = FV = KS'V'^3$$

$$\text{from which } F^3/T^2 = KS' = \alpha^3/\beta^2 \,.\, D^2, \text{ which gives}$$

$$S' = \alpha^3/\beta^2 \,.\, D^2 \,.\, 1/K. \quad \text{The value of } q \text{ is}$$

$$q = S'/S = 4\alpha^3 D^2/\beta^2 K \eta D^2 = 4\alpha^3/\beta^2 K \pi.$$

It will be seen that the "qualité" independently of diameter is a constant for all members of a family of geometrically similar airscrews.

Col. Renard has indicated, without actually proving the fact, that the quality q has a maximum value of :—$q = 6\rho^2$, ρ being the efficiency, which, since the efficiency cannot exceed unity, gives as a limit $q = 6$.

The experiments undertaken by Monsieur Riabouchinsky at the Aero-Dynamic Laboratory at Koutchino on this matter are most valuable and most conclusive. The results given in the following table concern the two-bladed airscrew of om 30 diameter turning to 30 revolutions per second and running in a current of air perpendicular to its axis. This airscrew had 40° blade angle, at the centre.

TABLE I.

Air Speed perpendicular to the axis of rotation.	Thrust Kg.	Power Absorbed H.P.	"Qualité" q.
0	0.036	0.32	0.08
2.5	0.050	0.33	0.19
4.2	0.065	0.30	0.50
5	0.074	0.29	0.80
6.2	0.082	0.28	1.16

Some Definitions.

If $V =$ the speed of ascent in metres per second, N the number of turns per second of the airscrew, $W =$ the relative speed of the air for an element of the blade—ds—situated at distance R from the centre of rotation.

The pitch or advance per revolution is :—

$$H = 2\eta R \times an\,(\beta + i).$$

The pitch diameter ratio is $h = H/D$.

The blade area ratio is the ratio between the projected area of the actual blade surface upon a plane perpendicular to the axis of rotation and the surface

of the circle swept out by the screw of diameter. The curves below give for lifting airscrews the general form of the curves of variation of the "qualité" expressed as a function of the four parameters. These are the speed of the perpendicular current of air, the blade area ratio, the pitch diameter ratio and the number of blades. These curves are arrived at from the work of Col. Renard and M. Riabouchinsky (Pamphlet No. 11, Bulletin de Koutchino).

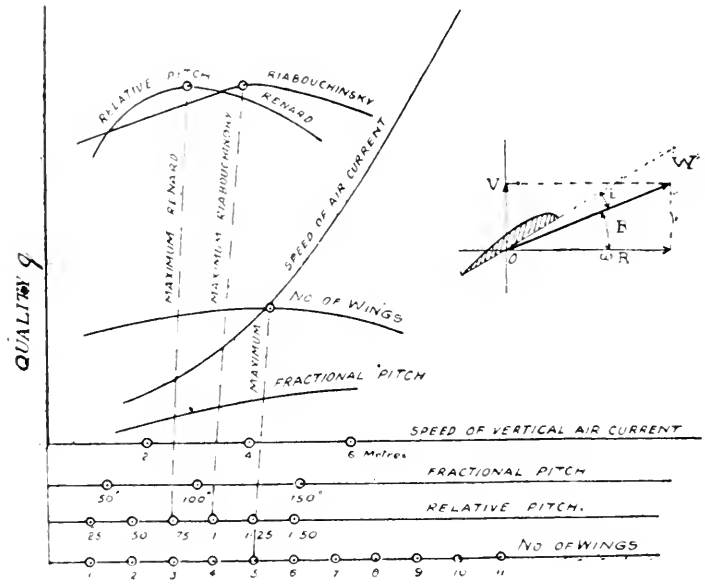


FIG. A.

(2) CONSTRUCTION OF HELICOPTERS.

If the manufacturers of toy helicopters are innumerable, the various investigators who have built full-size machines to verify their ideas are, on the contrary, very few. In France M. Louis Breguet on one hand and M. Paul Cornu on the other constructed machines which were for veritable "bench tests" of sustentational airscrews and which gave some interesting results. But the one, like the other, limited his efforts solely to solving one side only of the problem, and it has been the same with all the other investigators, in particular Mr. Cooper-Hewitt, who has made static tests on lifting airscrews driven by an electric motor in America. But since 1918 there have been brought forward several projects for the building of helicopters capable, not only of sustaining themselves but also of steering and of landing properly in gliding descent in case of a breakdown of the engines. The whole problem of the helicopter is summarised in these three conditions, of lifting, of horizontal translation and of gliding descent.

The Two Types of Helicopter.

It is necessary in any scheme for a helicopter to split up the lifting force between two airscrews or pairs of airscrews turning in opposite directions in order to avoid the rotation of the machine itself around the axis of the airscrew. One can conceive of helicopters under the three aspects shown in Figs. 1, 2 and 3, but

FIG. 1.

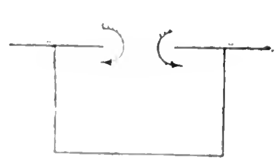


FIG. 2.

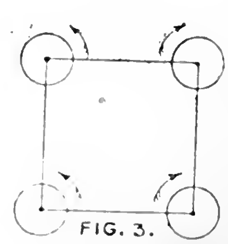


FIG. 3.

in reality there only exist two separate types (1) the machine with the single axis and (2) that with separate axis.

Advantages of the single axis: Great mechanical simplicity and consequent lightness.

Advantages of the separate axis: Better aerodynamic efficiency of the lifting airscrews.

Construction of Lifting Airscrews.

It has been seen that for lifting airscrews a very large blade area ratio was compatible with high efficiency. The optimum diameter for a lifting airscrew is 7 metres, and as far as the number of blades is concerned I have always considered that 4 was the best number. The blade of a lifting airscrew is comparable in dimensions to the wing of an aeroplane, but the loads which it has to carry are not similar. Its actual construction should be carried out with spars and ribs and particularly strong bracings, the whole covered with fabric and doped exactly like the wing of a monoplane. A blade should be designed to resist the following forces:—

(1.) The static loads which depend only on the weight of the machine. For these loads a suitable factor of safety would be seven.

(2.) Centrifugal loads. These are considerable in a screw of large diameter. A blade weighing 30 kg. 3 metres 50 radius with its centre of gravity 2 metres 50 from the axis is subject at a speed of 200 revolutions a minute to a centrifugal force

$$Fc = m\omega^2\mu = 30/9.81 \times [2 \times \pi \times 200/60]^2 \times 2.5 = 3{,}300 \text{ Kg.}$$

It is obviously necessary that the spars should be placed radially in the blade.

The weight of a lifting airscrew will, all other things being equal, obviously be greater than the wing of an aeroplane of the same surface.

During the recent construction of an experimental helicopter I have found that it was very difficult to build a blade of such a lifting screw giving a high factor of safety for a weight of less than 8 kg. per square metre. In this weight it included all the bracings, fabric, dope and varnish, in fact the whole weight of the rotating wing in working order. At the same time I believe that by reducing the diameter of the screws from seven to six metres and taking speeds of rotation of the order of 150 r.p.m., the weight per square metre can be reduced to 7 kg. Further, by using a biplane construction which allows a still further slight reduction of diameter and the replacement of bracing wires by well streamlined struts one will easily be able to reach 6 kg. per square metre. It is this figure which will be taken in the estimates which follow.

The peripheral speed of a lifting blade should not exceed 50 to 60 metres per second on account of the difficulties of construction. The peripheral speed of ordinary propulsive airscrews built of wood can easily reach 300 metres per second. All the before-mentioned considerations have to be taken into account before one can attempt the serious construction of a lifting airscrew. I give below by way of example the results of an official test upon a complete model one-seventh of full size of a lifting airscrew which I have built. The full-size wing has given under loading tests a factor of safety of 8.

TABLE II.

Date of Test—September 5, 1918.

Thrust kg.	3	8	15	18
R.P.M. of screws	480	778	1,008	1,169
Power absorbed at airscrew shaft H.P. ...	0.25	1.05	2.18	3.47

Barometer at time of test (corrected to 0 degs. C.) 776.5 mm. Temperature, 22 degs. C.

In order that two airscrews may be strictly geometrically similar they ought not to vary in their form under load. It is perfectly certain that the above model and the full-size rotating wing will not deform to the same extent when rotating since they differ in construction, but even if there is a difference it will be compensated for by the improvement due to the known superiority of full-size results over those deduced from model tests. In spite of the great width of the blades of this airscrew the figures obtained from it very closely conform to the theoretical formulæ of Col. Renard. In order to interpret the results we must apply the two fundamental relations:—

$$\text{Thrust in Kg.} \quad F = \alpha n^2 D^4.$$
$$\text{H.P.} \quad T = \beta n^3 D^5.$$

The results of the last column of the table of tests of September 5th, 1918, given for the model tested:—n_1 = 1,169 r.p.m. = T' = 3.47 H.P. and F_1 = 18 Kg.

The diameter and the maximum speed of rotation of the rotating wing of the full-size machine are $D = 7$ metres, $N = 160$ r.p.m. If we designate by T the power necessary at the shaft of the full-size screw and by F the corresponding lifting thrust we shall deduce from the results of the model test the following value for lift and the power:—

$$T = T_1 (N/n_1)^3 (D/d)^5 = 3.47 (160/1169)^3 (7/1.05)^5 = 115 \text{ H.P.}$$
$$F = F_1 (N/n_1)^2 (D/d)^4 = 18 \ (160/1169)^2 (7/1.05)^4 = 700 \text{ Kg.}$$

The actual helicopter which is in view uses two turning wings geometrically similar to that of the model tested, and each of these wings will then be capable of a thrust of 700 kg. for a power of 115 h.p. The supreme importance of this test lies in the fact that the actual helicopter as built only weighs 1,200 kg. and consequently each of the wings will only have to support 600 kg.

In addition, the useful power available per wing is 130 h.p., and finally the fixed incidence given to the blades of the model was only 10 degs. The excess of lifting force therefore is approximately 200 kg. for two wings together.

Stability of the Helicopter.

With reference to the centre of gravity of the helicopter we have to take account of three conditions of stability:—

(1) Longitudinal stability, which must be obtained around a horizontal axis through the centre of gravity and parallel to the plane of symmetry.

(2) Lateral stability; stability around the axis parallel to the length and passing through the centre of gravity.

(3) Rotational stability round a vertical axis through the centre of gravity.

In order to maintain its equilibrium in all positions a helicopter must possess rudder, elevator and special arrangements capable of producing effects similar to those due to the *ailerons* of an aeroplane. This question of stability is the most important one met with in the helicopter, and various solutions, several of which have already given valuable results, but into the details of which it is not now permissible to enter, are now being tested.

Equations of Sustentation and Practical Coefficients.

Calling

T = h.p. supplied.
p = weight of airscrews.
r = efficiency of transmission gear.
q = "qualité" of airscrews.
S_1 = surface of normal plane equivalent to the resistance to vertical ascent.
$K = 0.08$ = normal coefficient of resistance (flat plane).
F = thrust (lift) in Kg.
P = total weight of helicopter.
n = revolutions per second of airscrews.

Taking the case of a machine with two screws each 7 metres diameter, with four blades at the ground, the equation of equilibrium is

$$P = 2F = 2\alpha n^2 D^4.$$

If the force F becomes superior to P, the helicopter leaves the ground.

The acceleration on leaving the ground is:—

$$P/g \cdot \gamma = 2F - P - KSV^2.$$

The term KSV^2 is negligible at the start.

It has already been shown that the interpretation of the results of Table No. 2 gave for $D = 7$ metres and $N = 160$ r.p.m. $F = 700$ Kg. or $2F = 1{,}400$ Kg.

Weight of the Helicopter.

It may be taken that a helicopter, with 250 h.p. engines, will weigh in flying order 1,000 Kg. = P.

At the rate of 6 Kg. per square metre, the weight of the screws (of 40 square metres) will be $p = 6 \times 40 = 240$ Kg.

Experience has shown that the total weight P is about

$$P = 4p.$$

Speed of Climb at Start.

$$P/g \cdot \gamma = 1{,}400 - 1{,}000 = 400 \text{ Kg.}$$

from which $\gamma = 400 \times 9.81/1{,}000 = 3.80$ metres per sec.

The general equation for the vertical flight of a helicopter is of the form:—

$$P/g \cdot dV/dt + P + KSV^2\mu = \eta T_0/nD \cdot \mu.$$

Where η = efficiency of the transmission gear (= 0.95).
μ = the density of air at the altitude Z.
T_0 = engine power at sea level.

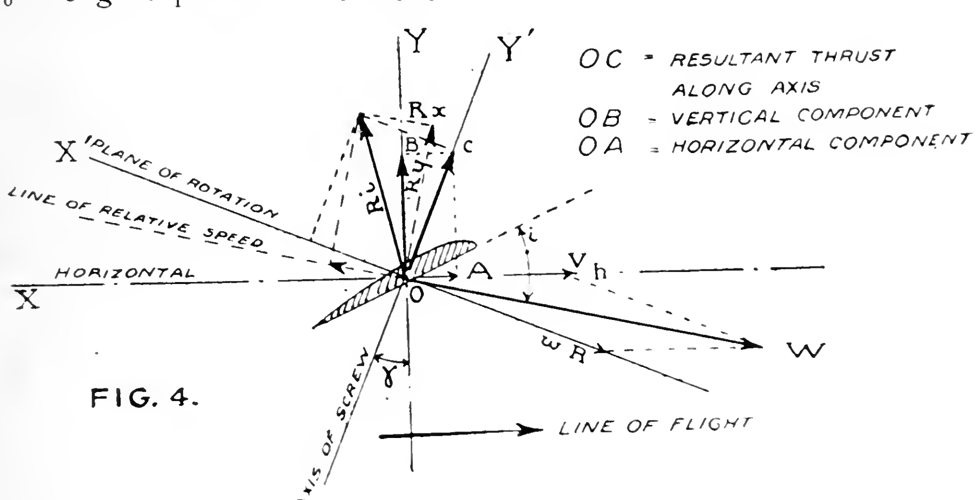


FIG. 4.

Speed of Horizontal Translation.

It will be seen that if 2F is the total resultant thrust along the inclined axis OY′ of the airscrews that the total horizontal component (OA for the element *ds*) will be for the whole machine:—

$$\Sigma OA = 2F \sin \gamma.$$

For $2F = 1{,}400$ Kg. $\gamma = 10°$.

$$\Sigma OA = 1{,}400 \times 0.174 = 250 \text{ Kg.}$$

If the resistance to horizontal flight is the equivalent of 2 sq. metres of normal surface the speed of translation will be

$$V = \sqrt{(250/0.08 \times 2)} \times 3.6 = 140 \text{ km.p.h.}$$

The lower the resistance to translation at movement the less is the inclination of the airscrew axis necessary to give any required horizontal speed.

Gliding Descent of a Helicopter with Stopped Motor.

This is the most vital point in the problem of the helicopter, for the adversaries of this type of heavier-than-air machines make it their essential argument that a safe descent under these conditions seems to them to be impossible. I wish to show in what follows that the vertical gliding descent of the helicopter with unclutched screws is actually possible, and to conclude that there should be no delay in solving this problem.

A descent with stopped motor can occur in two manners. First, airscrews declutched, turning round their axis as windmills, with a suitable incidence on the blades so that their direction of rotation may not be reversed.

Second with airscrews stopped in a fixed position as soon as the engine stops.

Fixed Screws.

I shall have little to say upon this second solution of the problem, in which I have very little confidence. It is equivalent to turning the helicopter into a very bad glider which will descend in an inclined path very much as an aeroplane does and this thanks to the use of appropriate gearing.

The total surface of the glider in this case will always be less than the sum of the real surfaces of all the blades of the airscrews. This "cut up" surface will have a very poor efficiency because of the very unfavourable conditions under which the blades have to work. The real surface available for gliding with fixed airscrews will also always be inferior to the surface swept out by the same airscrew in rotation. Even admitting that the blade area coefficient is equal to one, that is to say that the total surface of the blades is equal to the surface of the total swept circle, the component R_y of the resistance will be very much less than that corresponding to an ordinary wing of the same surface. Only the blade A (Fig. 5), *i.e.*, one quarter of the total surface, if it is a four-bladed screw, will be

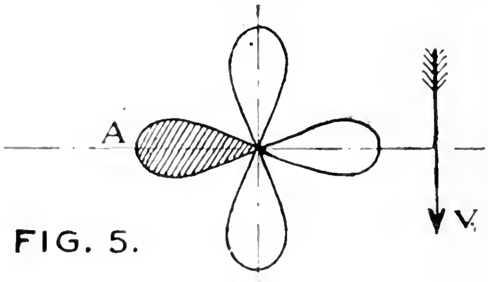


FIG. 5.

working under normal conditions. For the other blades of the airscrew the leading edge will be either the trailing edge or the tip of the blades.

The mean lift coefficient of such a set of surfaces will be very small and probably of the order of one quarter of that of a good biplane wing. In practice, if we take for the airscrew in question a minimum aspect ratio of $R/L = 1.75$ for $R = 3$ metres 50, we shall have the real surface for the airscrew fixed in position for the gliding descent of

$$S = \{ 3.5 \times \tfrac{1}{2}(2 + 1) \} 4 = 21 \text{ sq. metres.}$$

For the two screws of the helicopter we have taken as the total surface $S = 40$ metres square. For straight gliding descent taking a mean figure of 5° incidence and an air speed of 110 km. an hour (30 meters a second approximately) the equation for the lift is then $P \cos\theta = K_y S V^2$.

P = the total weight of the machine. S = lifting surface = 40 square metres. V = speed of translation along the line of gliding flight.

The lift of a good wing section for $\theta = 5^\circ$, $K_y = 0.03$.

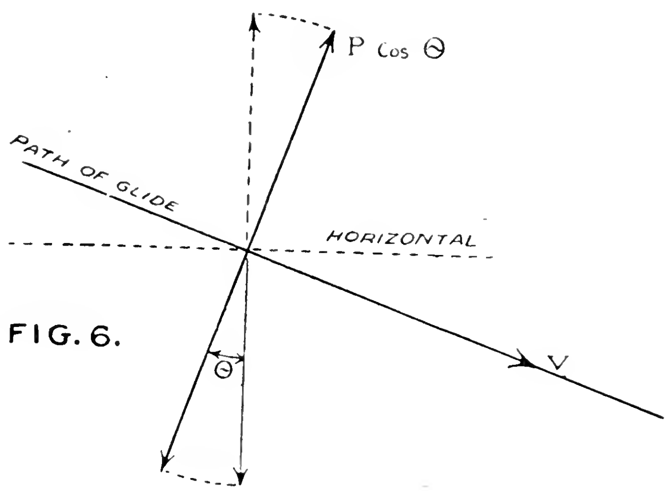


FIG. 6.

The lifting surfaces now in question work under such unfavourable conditions that it is only permissible to take a very low value of K_y, for instance that corresponding to the Bristol wing (Air Board, May, 1916), which for the angle of attack of 5° is $K_y = .007$.

Then

$$P = K_y S V^2/\cos\theta = .007 \times 40 \times 30^2/0.996 = 255 \text{ Kg.}$$

We have then a glider which is not capable of sustaining more than 6.5 kilos. per square metre. It has been seen above that the airscrews themselves weigh at least 240 kilos. and that the total weight of the helicopter is about four times this weight—that is to say, about 960 kilos. It is, therefore, extremely likely that such a machine with stopped motors will dive to the ground nearly vertically and at a high speed. If we take it that a normal glider can carry 30 kilos. per square metre, it will be seen that the efficiency of the fixed airscrew system is about five times less than that of the normal glider, and that it is obviously too low.

Finally the mechanical difficulty of stopping and fixing the airscrew instantaneously in the desired position will be very great, and, more than that, very serious disturbances of the normal operation of the machine are to be expected at the same time.

Case of the De-clutched Airscrews.

This is the only rational solution of the problem of controlled descent of the helicopter with stopped engines. It is proposed to examine in detail this important subject. In the first place, centrifugal de-clutching—that is to say, use of a clutch which operates in accordance with the speed of the engine—is obviously suitable,

because the operation is automatic and immediately frees the airscrews from the engine as soon as this stops from any cause whatever. Two cases have to be considered.

Stoppage of the Engine during Vertical Ascent.

Immediately on the stoppage of the motor the balance between the lift of the airscrews and the weight of the machine is destroyed. If the readjustment does not occur immediately a catastrophe is inevitable, because the screw de-clutched and still turning in the same direction tends to stop and then to reverse. There is therefore produced momentarily a break of continuity in the equilibrium of the system, for the lift will drop to zero at the period of reversal of the airscrews. Fig. 7 represents upon one element of the blade situated at the distance R from

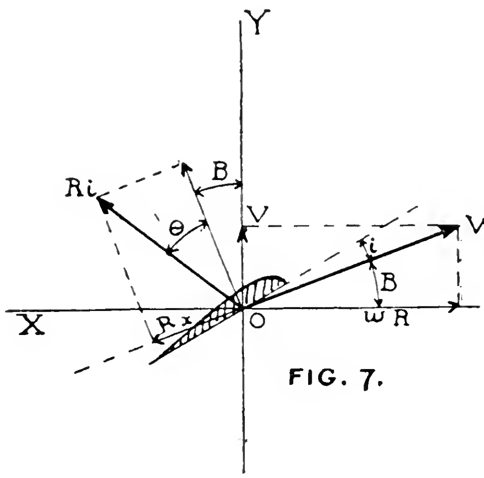


FIG. 7.

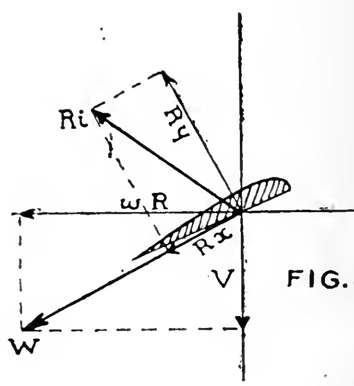


FIG. 8.

the axis of rotation the resultants of the reaction of the air during normal ascent. If we admit the hypothesis that the machine will not be out of equilibrium in its path of descent during the period of zero lift corresponding to the reversal of the screws, there must be a new state of equilibrium characterised by Fig. 8. The only acceptable solution, however, is, it can be seen, that of Fig. 9, for this allows

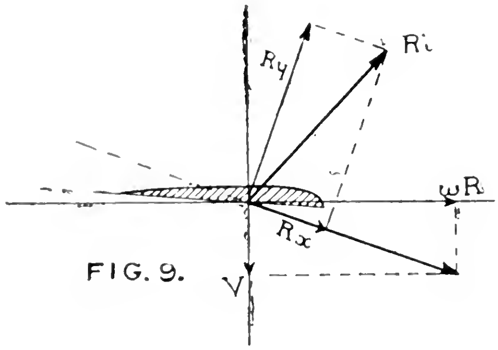


FIG. 9.

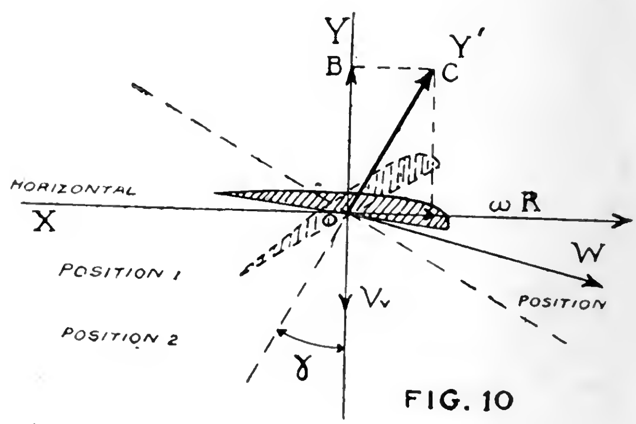


FIG. 10

maintenance of the same direction of rotation of the airscrews as in ordinary flight, with stopped engine. The lifting force is transformed immediately into a braking force, and no accidents are to be feared under these conditions.

The normal descent of the helicopter with stopped engine should be made with de-clutched airscrews and with blades readjusted to give the same direction of rotation.

Engine Stopping During Horizontal Flight.

It has been seen in the consideration of lifting force that the angle γ is very slight, and that a small inclination of the axes of the airscrews provides a horizontal component sufficient for the forward movement of the machine. Let the vertical speed be considered zero at the moment of the stoppage of the engines. The element—*ds*—of the blade at this instant will be at the position (1) of Fig. 10. The relative speed of the blade—*w*—will diminish rapidly with the angle *i*, as will the component O.B. (the lift component). By use of the elevator one can immediately bring the axis of the airscrews back to the vertical, and $C.Y^1$ and $C.X^1$ will coincide with C.Y. and C.X., and the machine will no longer move forward. At this moment the element *ds* occupies the position 2. The vertical speed of descent for the first second is large relatively to ω, which diminishes very rapidly. The angle of incidence *i* may at this moment have very large value, something in the neighbourhood of normal attack, and we have therefore arrived at the position 2. In the same case is that already treated—stoppage of the motor during vertical ascent, and the diagram of Fig. 9 gives the solution desired. It is to be remarked that position 3, which is reached as the last manœuvre for vertical descent, approaches position 1 for horizontal flight, but with position 1 the axis of the airscrew is inclined, and in position 3 this axis is vertical. Even in this very general case it can be seen that the braked descent presents no serious difficulty, and that the problem is quite simple to solve.

It is equally possible to conceive in the case of the helicopter with declutched screws a spiral gliding descent. In this case the machine descends in spirals at a uniform speed, and turning round a vertical axis and the centre of gravity will describe a helix, and in order that equilibrium may be maintained it is sufficient that the resultant total velocity shall be vertical, and that its line of action shall pass through the centre of gravity of the whole spiral system.

In the equations of equilibrium of the helicopter it will be necessary to take into account the centrifugal forces due to the rotation of the whole machine, which are more or less important as the radius of the cylinder of revolution becomes greater.

The vertical gliding of the machine at a uniform speed produces no supplementary inertia forces. All other things being equal, it is perfectly certain that in spiral descent the vertical speed of gliding will be sensibly less than in the case of the vertical gliding descent.

From recent experiments it appears, and calculations confirm the results of these experiments, that a good lifting airscrew used as a brake in this way at the optimum angle of attack will give for two blades a breaking force

$$F = 0.2 V^2 D^2$$

For a four-bladed screw we shall have 2F, the braking effect being proportional to the surface. It has already been said that for the best lifting airscrew D = 7 metres. The table below shows the very great increase in the braking effect F with increase of the vertical speed of descent. I have added to the same table the weights for an airscrew 7 metres diameter with four blades of 16 square metres surface, weighing 6 kilos. per square metre, or 96 kilos., in round figures 100 kilos. The last column gives the excess of braking force over the weight of the screw itself, which is available for descent.

Velocity of ascent, metres per second.	Braking Force $F = 2 \times 0.2 V^2D^2$. kilos.	Weight of Screw. kilos.	Excess F per screw. kilos.	Excess F for the two screws. kilos.
3	178	100	78	156
4	315	100	215	430
4·5	400	100	300	600
5	500	100	400	800
6	700	100	600	1,200

It has been shown that the total weight of the helicopter is roughly four times the weight of the screws, or in the case which is now being considered, 800 kilos. For the speed 4.5 metres per second we have therefore descent in equilibrium.

What is Safe Limit for Vertical Descent?

It has been claimed by certain persons that 3 metres per second was the limiting speed allowable for descent, and that the human organism could not tolerate without serious inconvenience more than 4 metres. I would simply remark here that it is admitted in fact that a normal aeroplane is considered to allow of safe landing when the horizontal speed near the ground is 110 kiloms. per hour and its vertical speed is 4 metres per second. In gliding flight a horizontal speed of 180 kiloms. is normal and the vertical velocity of descent is about one-tenth of this value, in this case 5 metres per second. All good pilots are unanimous in stating that landing under these conditions is perfectly supportable.

The Inter-Allied Commission, in their reports upon parachutes for aircraft, take as a basis for their investigation the following condition :—" Speed of descent less than 5 metres a second," which is to say, a speed of descent up to 5 metres a second can be tolerated, and finally, which is very important, the Service Technique l'Aéronautique Française, in their specifications for new aircraft, impose upon the under-carriages of night-flying aeroplanes the following conditions :—" The elastic connections shall be designed for forces which shall not exceed those due to the machine falling vertically from a height of one metre." That is to say, that for a night-flying aeroplane the vertical speed of contact with the ground may attain, without danger, $H=1$ metre $V=\sqrt{2gH}=4.45$ metres a second. It is therefore perfectly possible, using already known methods of shock-absorbing, to consider that a safe vertical speed of descent for a helicopter is between 4.5 and 5 metres a second.

For any airscrew we see that the braking effect is directly proportional to the square of the speed of descent. If for the screw of diameter 7 metres a speed of descent is $V = 2.5$, braking force $F = 122$ kilos. In this case it would become for $V = 5$ metres a second, $F = 488$ kilos. When the speed of vertical descent becomes twice as great the " braking " force becomes four times greater.

Conclusion.

In the golden book of the Science of Aeronautics, where there are already inscribed those glorious conquests which we know as " balloons," " airships " and " aeroplanes," the last page is reserved for the helicopter.

In a few months the helicopter will enter upon a phase of decisive achievement.

A fact which is remarkable is that with the helicopter no new principle is involved. Everything is known, and it is merely a question of adaptation. The progress of aerodynamics during the war will find here a direct application. Powerful and light engines of a high power to weight ratio, the improvement in the qualities of wings, the use in construction of light alloys will all play their part.

There is one single shadow over the picture; it is that of the difficulties of actual mechanical construction. The helicopter will be an instrument of precision whose parts will be united one to the other by members carefully constructed and minutely calculated. This heavier-than-air machine will be more than any other dependent upon craftsmanship.

But we have already solved an even more delicate problem in the construction of the aero-engine, that veritable masterpiece of skilled and intelligent workmanship.

What will be the first use of the helicopter, the most important, the most

desirable? My own idea is that the first helicopter will be called more properly hydro-helicopter. For marine navigation work the value of the helicopter is of the very first order. The helicopter will be the eye of the ship. To state only one example of its use, I can see in the near future a flotilla of helicopters rise from the deck of a liner in distress, and take into security, several hundred metres above the angry waves, all the passengers, women and children, while they wait for a rescuing ship.

For naval purposes applications for the helicopter are of capital importance, for seeking out and for bombing submarines, for fire control, for inter-communication purposes, and for the carrying of supplies between squadrons the helicopter will necessarily be an invaluable auxiliary.

The probable characteristics of the first type of helicopter to be constructed will be something as follows :—

Total weight	800 kilos.
Useful weight, pilot and armament	150 kilos.
Engine power	120 h.p.
Climbing speed	3 metres a second.
Horizontal speed	100 kiloms. an hour.

The construction of such a machine ought not to be far off, for—and this is, I consider, very important, even if all the problems which are encountered in the construction of the helicopter are not yet completely solved—the hydro-helicopter is nevertheless already possible and usable.

"The Times," in an editorial notice on November 3, 1920, dealing with the question of landing an aeroplane on the deck of a ship, terminates its article with these words :—"One can therefore have no doubt as to the importance of the helicopter."

It remains for me only to thank you very sincerely for your very kind attention, and I hope you will allow me, in finishing, to state that it is my convinced opinion that the year 1921 will see the realisation of the first practical flight of a helicopter flying machine.

DISCUSSION.

Dr. H. C. Watts expressed his thanks to the Author for his kindness and courtesy in coming there to lecture on this interesting subject. Whilst he (the speaker) had not been altogether convinced by what the Author had said, yet he had been interested. The subject of helicopters was an old one, but he thought that too frequently discussions concerning it were characterised by a lack of appreciation of the real problems involved. The subject was often discussed and dismissed as being only a propeller problem of obtaining a high thrust per horse-power. This side of the problem, he ventured to say, had for some time past been considered by propeller designers as solved for low altitudes. It would have been appreciated from this lecture that that side was a small part of the problem. Given a certain engine horse-power the essentials of high thrust were well known though the lecturer had not clearly stated them. Mons. Damblanc had concluded that for any given propeller the lift varied inversely as the rate of revolution. A more general and equally true statement was that for any propeller of a geometrically similar series the lift varied inversely as the tip speed. The further essentials were a large diameter and an aerofoil section giving as high a lift-drag ratio with as high a drag coefficient as possible.

The gross lift per horse-power might be increased indefinitely by increasing the diameter, but since the nett thrust was the gross thrust less the weight of the wings, there was some optimum diameter above which although the gross lift

increased, the weight of the wings increased to such an extent that the nett thrust decreased.

The lecturer had placed that limit for 130 h.p. at 23ft., and at this limit his wings weighed about 1½lbs. per sq. foot. The lift he obtained worked out at 13½lbs. per horse-power. This was not an exaggerated figure. He (the speaker) would expect a higher figure. He thought 20lbs. gross lift per horse-power might easily be obtained. If not, the helicopter would be of no particular value. The weight of the helicopter proposed by M. Damblanc was 2,640lbs.; the lift at ground level was about 3,000lbs. The ceiling could therefore be little more than 5,000 feet. At the ceiling all the thrust would be required merely to support the machine and the translational velocity would therefore be zero. Under these conditions its powers of manœuvring would be almost negligible, and he put it to the meeting that an aircraft with only a ceiling of 5,000 feet, with no translational velocity at that height and with little power of manœuvring, had no serious military value. It would be particularly vulnerable to anti-aircraft fire and to attack from quite ordinary aeroplanes. Provided the helicopter could be maintained in steady level flight, he (the speaker) thought the lecturer's estimate of forward speed not over-estimated. This, however, only applied to ground level. As he had already mentioned, the speed at the ceiling of the aircraft must be zero.

The more serious and more difficult helicopter problems were those of stability and rate of descent with engines cut out.

In vertical ascent the natural pendulum stability of the helicopter might conceivably be of some use but would be of small value for level flights. As regards longitudinal stability the problem was similar to that of an ordinary aeroplane. Close examination of the problem would show that as the nose of the aircraft went up the centre of lift travelled forward, thus introducing a positive moment of increasing magnitude. This could be met as in the ordinary machine by introducing a negative tail moment. At the low flight speed near the ceiling, however, the helicopter must be dangerously unstable. As regards the lateral stability he preferred not to speak without further consideration.

He had not been convinced as to the possibilities of safe descent with the engines cut out. In the first place, according to M. Damblanc's design, the propellers were automatically declutched when one engine cut. The pilot must then quickly bring the helicopter to a horizontal position and also alter the pitch of his propeller to prevent reverse rotation. All this must be done before the aircraft got into an uncontrollable position.

The lecturer has admitted that he was not hopeful about a safe descent with fixed propellers. He (the speaker) agreed with him, but he was no more convinced about safe descent with propellers freely rotating. In fact, unless some resistance was introduced to absorb the power generated by the windmilling of the propellers the resistance to falling would almost certainly be less than with propellers fixed. The velocity of five metres per second when approaching the ground appeared to him too high. In English units it was some 11 miles per hour—a good speed for an ordinary push-cycle. One obtained a fairly good idea of force of impact by imagining oneself riding a push-cycle loaded with all the weight of the helicopter into a brick wall at full speed. Even with good shock-absorbing devices the speed seemed too high for practical purposes.

When one had solved all these problems there was still the question of mechanical design, and he thought that this alone would be sufficient to deter anyone not possessing the optimism and the courage of M. Damblanc.

But if there was anything in this idea and if there was any use in model experiments, this was surely a case for model rather than full size trials. In this way many of the doubtful points could be settled and a large amount of information could be obtained such as the resistance of a propeller to a side wind and, for the purposes of stability calculations, the movement of the centre of thrust as

the plane of rotation of a propeller is inclined to the wind direction. The expense and the risk to life involved in building a full-sized machine could thus be avoided.

Although he had been critical, he again thanked M. Damblanc for his lecture.

Mr. F. HANDLEY PAGE said, in discussing the helicopter, that there were two phases to talk about. One was the problem of rising and alighting, the other the problem of forward movement through the air. Most people seemed to attach importance to the question of rising and alighting, and though it was, of course, important from a safety point of view to alight safely, yet undue importance was attached to hovering in the air. Purely from the point of view of commercial air transport, one did not want to remain stationary in the air. It was only from a military point of view—and even then limited in use—that it was of any value.

In dealing with the problem of forward movement the question as to which was better, the helicopter or the ordinary aeroplane, was one that would be solely determined in practice, the ultimate choice being for the type which gave the highest forward speed with a given useful load per horse-power. Apart, however, from actual practical data, which were not yet available for the helicopter, it seemed to him that from the helicopter mechanism photograph shown, an aeroplane must be more efficient from a structural point of view. The aeroplane must therefore have a less structure weight and a greater proportion of useful weight-carrying capacity. The head resistance would appear less, and therefore higher speed could be obtained with a given horse-power. This would seem to point to the conclusion that with an aeroplane a greater useful load could be transported with a given horse-power at a given speed, or alternatively with a given load and horse-power a greater speed could be obtained.

It was questionable from an operational point of view, as he had already stated, whether the helicopter's power of getting off the ground quickly was an advantage. As commercial air transport developed, longer distances would be flown, and the question of starting and alighting would become of lesser importance. The aeroplane would therefore be comparable to soaring birds, such as the vulture or the albatross, which rose from the ground with difficulty but flew long distances, and not comparable to the sparrow, which flapped its wings and flew more or less vertically upwards for short distances.

The value of the helicopter was, to a large extent, discounted by recent improvements in high lift wings. Now that lift coefficients with this new type of plane had been obtained of, approximately, 2—measured in absolute units—the problem of getting off the ground quickly was much easier than in the old days, when a lift coefficient was rarely obtained higher than .7 or .8, even with a high lift wing. With such high lift planes one could get off the ground more quickly and climb at a very much steeper angle.

There was also the difficulty of controlling the helicopter when in the air. Everybody in favour of the helicopter said, "How beautiful it is; you can go straight up very quickly," but they overlooked the fact that if one was not very careful when the motor stopped he could come down equally quickly. To avoid this one had to plane down with the propellers declutched and rotating. To do this, however, involved altering the altitude of the machine and reversing the curvature of the blades. Such warping schemes had not been a success in the ordinary aeroplane, and for success in a helicopter the mechanism would probably have to be replaced by ailerons. It struck one very forcibly, however, that the problem of alighting was a very serious one with the helicopter.

In spite of all the criticism directed against the helicopter in general, one must admire the courage of anyone who had gone forward and constructed a machine with all the intricate mechanism which comprised Monsieur Damblanc's helicopter, and one would wish him every success.

One final question he would like to ask was—had the machine ever flown?

Mr. M. A. S. Riach said the type of heavier-than-air flying machine known as the helicopter was one in which he was greatly interested. To be able to rise and land vertically strongly appealed to the imagination, and they had all read Jules Verne's romance, "The Clipper of the Clouds." There appeared to be three main difficulties which must be overcome before the helicopter could evolve into an engineering proposition. They consisted of (1) the problem of sufficiently slow descent, *i.e.*, landing, (2) the accomplishment of horizontal flight as the aeroplane, and (3) stability whilst in the air under all conditions. Of these three, the first (the problem of safe descent) could be overcome at least theoretically by employing large enough diameter lifting propellers, and this then reduced the question to one of structural design and the limitations of size imposed in practice. The second (horizontal flight) seemed feasible in theory, but probably would be accomplished with safety if sufficient attention were directed to the helicopter. The third (stability) still awaited solution along analogous lines to those adopted by Bryan for aeroplane stability. He inclined to the view that 2 and 3 were largely inter-related and would be successfully solved during the next few years. This left the problem of safe descent to be considered. Perhaps it would be news to some that the helicopter must, if stable, reach a "terminal velocity" of descent after the motor had stopped, provided that the lifting screws were free to rotate independently of the engine. As an illustration, a stone falling from rest under gravity would, after any distance of fall, have acquired a known velocity, and in consequence it would possess a definite amount of kinetic energy. Suppose that a second body of equal mass is free to fall from the same height at the same time. If this second body, by some means, be caused to rotate about its axis of fall and the cause of its rotation be the relative air velocity due to its falling motion, then such rotation was indirectly caused by gravity. After it had fallen the same distance from rest as the stone, it would be both rotating and falling. Hence it would possess a rotational energy and a kinetic energy, the sum of the two energies being equal to the energy of the stone of equal mass. So that evidently the velocity of fall of the rotating body must be less than the velocity of fall of the stone for a given distance of fall. Now the helicopter whilst descending was the rotating body, and therefore it would fall slower than a stone by virtue of its rotation. This led to the paradox: If the helicopter rotated sufficiently rapidly it would not fall at all! Actually, of course, it must fall in order to rotate. But a "terminal velocity" was soon reached, after which the helicopter fell like a parachute. It was for engineers to make such "terminal velocity" sufficiently small to permit of safe descent and landing. This, he imagined, meant the use of excessively large lifting screws, unless some alternative could be produced. Recently attention had been directed to the possibilities of the steam plant applied to aircraft. The helicopter conceivably might be helped by using, instead of the conventional aero-engine, a steam system. He was thinking particularly of the landing difficulty. If a steam engine and boiler of the fire-tube type, which held a large quantity of water, were used, the helicopter could descend in perfect safety even after the fuel supply had been cut off by utilising the reserve steam energy in the boiler to drive the lifting screws. The danger of fire in the air was also greatly reduced with a steam plant. As regarded (3) the stability question generally for the helicopter, he was not in a position to discuss. It would have to be worked out along the lines of aeroplane stability. With regard to (2) horizontal flight, the easiest and most rational way of securing horizontal flight was by inclining the plane of rotation of the lifting screws away from the horizontal, in whatever direction it was desired to travel. This brought in at once all kinds of new conditions as regarded the working of the lifting screws on account of the change in relative velocity as each blade rotated. Experimental work was required here. For lifting screws having two blades, a periodical motion was introduced, and the horizontal velocity of the helicopter became a function of the time, having maximum and minimum intensities. The multi-bladed propeller might be useful here, for then the period was very small and the horizontal velocity became nearly uniform. A helicopter moving sideways

was analogous, as regarded its lifting screws, to a side wind on an aeroplane propeller. He congratulated Mons. Damblanc upon the system he had adopted of using two lifting screws of equal diameter rotating side by side. It was, he thought, the most intelligent arrangement of any.

Captain GOODMAN CROUCH said that one could only have great admiration for a pioneer who attacked a problem of this kind with confidence in his ability to solve all the incidental problems connected with it. It was his opinion, however, that a solution of these problems should be sought before attempting the construction of an aircraft of this type.

He suggested that possibly the value of the paper would have been increased as far as an English audience were concerned if time had been available for the translation of the various French symbols used. The problem of descent had only been briefly touched upon, and it had perhaps not been realised that there were a great many mechanical difficulties, and even on Mons. Damblanc's figures no very satisfactory landing could be hoped for, quite apart from the difficulties of application, and the constructional and mechanical problems involved in an attempt to secure adequate stability.

The CHAIRMAN announced that the Lecturer would reply to the discussion in writing. He proposed a hearty vote of thanks to Mons. Damblanc for his kindness in coming there to give his Lecture, and for the interesting information he had given them. He thought the members would all join in wishing him luck in his forthcoming experiments, and hoped his rate of descent would prove both theoretically and practically suitable. They had also to thank Capt. Sayers, who had discharged a very difficult task. He had not had much time either to translate the Lecture or go through with the Author the various points in the Lecture that had to be explained, but he had done it extremely well.

[*M. Damblanc's reply has not been received at the time of going to press. It will be printed in an early issue.*—EDITOR.]

On the motion of Brig.-Gen. R. K. BAGNALL-WILD, a vote of thanks was also accorded Sir Edward Ellington for presiding.

A NOTE ON THE "INFLOW" THEORY OF THE AIRSCREW.

BY M. A. S. RIACH, F.R.AË.S., ASSOC. INST. N.A.

The following note has been written partly by way of a commentary upon Dr. H. C. Watt's recent article, in the July number of the AËRONAUTICAL JOURNAL, entitled, "A Note on the Theories of Screw Propulsion," and partly by way of an explanation of the apparent inconsistency of the "inflow" theory of the airscrew.

Consider an element of a propeller blade situated at a radius of x from the boss centre of the propeller and having an angle of ϕ between the chord line of the blade section and the plane of rotation. The form of the blade section is considered to be that of an aerofoil, of which the characteristics are known from wind channel experiments upon a model of the same geometrical form (Fig. 1).

We wish to apply these wind channel data to the propeller blade element with rigorous consistency, *i.e.*, as far as the two respective régimes of the propeller and the aerofoil permit.

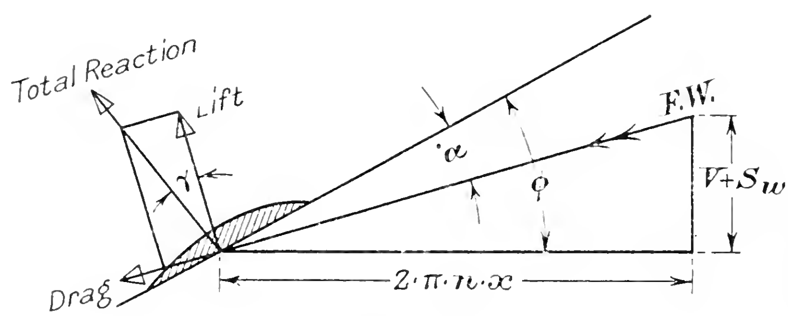


FIG. 1.

All rotational impressed velocities are here ignored. They are in any case quite small and do not affect the present argument, they serve purely as corrections.

Let α, Fig. 1, be the angle between the chord line of the blade section and the "free wind" direction F.W. marked with the double arrows. Then F.W. is defined as being the analogous free wind direction of the simple aerofoil as tested in the wind channel.

V is the axial velocity of advance through the undisturbed air, *i.e.*, the velocity of the aircraft.

$2\pi nx$ is the circumferential velocity of the blade element due to its rotation, where n = revolutions per second of the propeller.

S_w is the interference flow caused by the interfering action of the blades upon each other. It is the only real physical inflow which requires consideration here.

So far all is harmony, and no inconsistency exists in the analogy drawn between aerofoils and propeller blades the sections of which are aerofoils.

Now we require, among other things, to be able to calculate the thrust exerted by the blade element.

Let us apply the aerofoil analogy and with it the wind channel data. Let :—

Ky = coefficient of lift of aerofoil, in non-dimensional units.
$\tan\gamma$ = drag/lift ratio of aerofoil.
b = chord width of aerofoil.
ρ = mass/density of air.

Then the lift on the aerofoil section, at radius x, will be :—

$$ky\,\rho\, b\,\delta x\,\left[(V+S_w)^2+4\pi^2n^2x^2\right]$$

or

$$ky\,\rho\, b\,\delta x\;\; 4\pi^2n^2x^2\;\;\sec^2(\phi-a)$$

Now Ky is a function of the angle of attack a, so that we know the value of the above expression when we know the value of a. At present we do not know the value of a. How are we to find its value?

Alternatively it is seen that we know a if we know S_w, *i.e.*, if we know the magnitude of the interference inflow velocity. But as yet we do not know the value of S_w either.

From considerations of momentum we can *attempt* to estimate the thrust of the blade element independently of aerofoil data.

Let δM denote the mass of air which is engaged per second by the blade element and from which it derives (in conjunction with the impressed axial slip velocity) its thrust.

Let S_2 denote the axial slip velocity imparted by the blade element to this elementary mass of air δM.

Then the axial thrust of the blade element is $\delta M\,.\,S_2$.

But, returning to the aerofoil estimate of axial thrust, we see that we can measure the same quantity from the aerofoil data. It is (see Fig. 1) :—

$$\text{Lift}\times\cos(\phi-a)-\text{drag}\times\sin(\phi-a)$$
$$=\text{lift}\times\cos(\phi-a)\times\left[1-\tan\gamma\tan(\phi-a)\right]$$

and $\tan\gamma$ is also a function of the angle of attack a,

$$=Ky\,\rho\, b\,\delta x\; 4\pi^2n^2x^2\,\sec(\phi-a)\;\left[1-\tan\gamma\,\tan(\phi-a)\right]$$

Since however, by definition, this same quantity is measured by $\delta M\,.\,S_2$, the two quantities must be equal. Therefore we are justified in equating them. Thus :—

$$\delta M\,.\,S_2=Ky\,\rho\, b\,\delta x\;\;4\pi^2n^2x^2\;\;\sec(\phi-a)\;\;\left[1-\tan\gamma\,.\tan(\phi-a)\right]$$

Now, to be of any value to us in our search for a, we must know something about δM and S_2. Take δM first. Let us *assume* that the quantity of air passing through any annulus per second at a radius of x is

$$2\pi x\,\delta x\,(V+S_w)$$

That is the volume of air per second engaged by N blade elements (at corresponding radii x on each of the N blades) is the product of the axial velocity $(V+S_w)$ and the annular ring area $2\pi x\,\delta x$, where N = number of blades. This, it is true, is an arbitrary assumption, but some *similar* kind of assumption must be made if we are to proceed. The particular assumption made in any case does not materially alter the argument.

$$\therefore\;\delta M=\left[\rho\, 2\pi x\,\delta x\,(V+S_w)\right]/N$$

Hence, substituting for δM, we get :—

$$\therefore\; Ky=\left[S_2\,.\,(V+S_w)\cos(\phi-a)\right]/\left\{Nb2\pi n^2x\left[1-\tan\gamma\,\tan(\phi-a)\right]\right\}$$

But, from Fig. 1, we know that

$$V+S_w=2\pi nx\tan(\phi-a)$$

so that substituting this value above, we get :—

$$\therefore\; Ky=S_2\sin(\phi-a)/\left\{Nbn\left[1-\tan\gamma\tan(\phi-a)\right]\right\}$$

Now in this formula we know the values of each of the following symbols:— ϕ, N, b, n, and both Ky and $\tan\gamma$ are functions of a.

Hence in this equation we have got Ky as a function of a and S_2, and certain constants ϕ, N, B, and n. Suppose that we knew S_2 completely, then we should have simply an equation giving Ky as a function of a. But from the aerofoil data, obtained in the wind channel measurements of lift and drag coefficients, we have *another* equation giving Ky as a function of a. Hence these two equations combined completely determine a, and hence also Ky and $\tan\gamma$, in any case.

But we do not yet know anything about S_2, and until we *do* know something about it we cannot realise the above solution.

We now come therefore to the crux of the whole matter. We have evidently got to make another assumption. Let us then now *assume* that:—

$$S_2 = \lambda \, . \, S_w$$

where λ is an experimental "constant."

Then, since:—$V + S_w = 2\pi nx \tan(\phi - a)$.

$$\therefore \; S_w = 2\pi nx \left[\tan(\phi - a) - V/2\pi nx\right]$$

$$\therefore \; S_w = 2\pi nx \left[\tan(\phi - a) - \tan A\right], \text{ where } \tan A = V/2\pi nx$$

$$\therefore \; S_2 = \lambda 2\pi nx \left[\tan(\phi - a) - \tan A\right]$$

Hence, substituting for S_2, we get:—

$$\therefore \; Ky = \lambda 2\pi x \sin(\phi - a)\left[\tan(\phi - a) - \tan A\right]/Nb\left[1 - \tan\gamma \tan(\phi - a)\right]$$

This equation gives us all that we require, when λ is known. If λ is known, experimentally say, then we have here an equation giving Ky as a function of a only and certain constants x, ϕ, A, N and b; $\tan\gamma$ is a function of a also. We have then only to employ this equation for Ky in conjunction with the wind channel curve of Ky against a to solve completely for the values of Ky, a and $\tan\gamma$. Knowing in this way the value of a we also know immediately the value of S_w and hence also of S_2. Both the lift and thrust, etc., on the blade element are thus found, and we can proceed to completely analyse any type of airscrew under any conditions of working. Conversely we can design airscrews to fulfil any given requirements upon the same theory.

This is a brief outline of the "inflow" theory, correctly understood. There is no inconsistency of treatment to be found anywhere in the foregoing exposition. It is all perfectly straightforward and logical.

Where then did the original "inflow" inconsistency originate?

It originated, probably, in the conception of the physical meaning to be attached to the equation:—

$$S_2 = \lambda \, . \, S_w$$

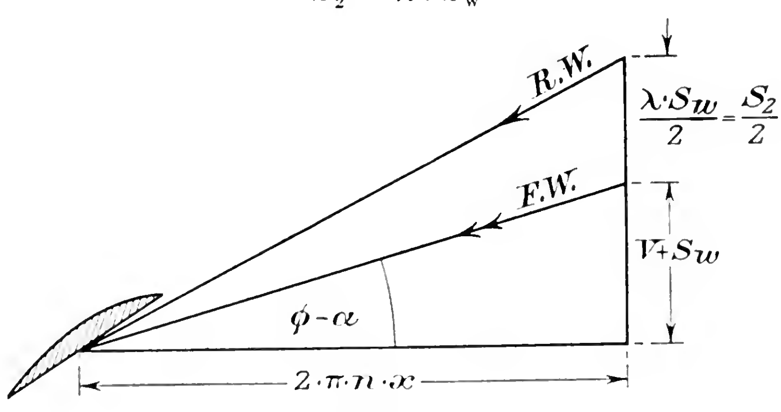


FIG. 2.

Consider Fig. 2, particularly in the case when $\lambda = 2$. For then the slip velocity S_2 becomes equal to twice the inflow velocity, and if we further suppose

that, in all cases, part of the slip S_2 is present in front of the blade element and that it has reached a value on the disc surface of *one-half* its full value, then it is seen that if $\lambda = 2$ the amount of the slip S_2 which is present just in front of any element of blade is $\frac{1}{2}S_2 = \frac{1}{2}\lambda S_w = S_w$. Thus, under such conditions—and they are quite possible conditions—we arrive at the result that the slip velocity S_2 is twice the inflow velocity S_w, and that one-half of its full value is attained at the disc surface, such value being then equal to S_w.

We then redraw Fig. 2 and get Fig. 3.

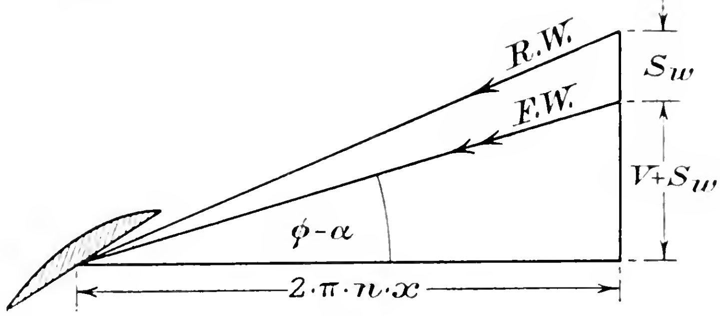


FIG. 3.

It should now be evident how the confusion of thought originated in the first "inflow" treatments.

From Fig. 3 it is evident that the S_w, between the R.W. and F.W. lines, is a *locally* produced velocity produced by the blade element itself. On the other hand, however, the S_w, between the F.W. and the base lines, is *not* a locally produced velocity at all but a velocity produced by the action of the propeller *as a whole* and caused directly by blade interference. This difference being clearly understood, there can be no possible inconsistency present in the treatment.

Suppose, however, that we redraw Fig. 3, and *omit* the first S_w, thus:—

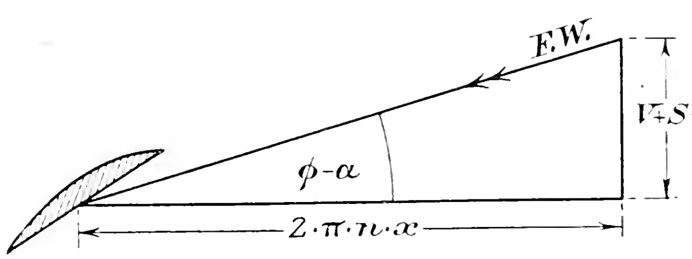


FIG. 4.

Then, with only this figure in mind, if we try to evolve an "inflow" theory we shall—more likely than not—fall into the same inconsistency of régime as that of the original theory, more especially if we have no very clear or definite ideas about the part played by blade interference in producing the inflow velocity.

We shall be very apt to fall into the inconsistency of confusing two distinct velocities—namely, interference inflow and thrust slip—and our Fig. 4 will hardly help us to distinguish between these two velocities in our own minds, since only *one* impressed velocity is shown!

We might then perhaps be forgiven for making the following illogical statement of affairs:—

There is some kind of an inflow velocity present we know from experience. Call this inflow velocity S_w, Fig. 4. The total slip velocity should satisfy thrust, and part of this slip velocity is probably present in advance of the propeller, and at the disc surface reaches a high value. Assume that this value is 50 per cent.

of the full slip velocity. Then, of course, obviously, this 50 per cent. value of the slip *must be the inflow* S_w! The climax of inconsistency is thus easily reached.

It was easy—especially when the whole conception of "inflow" was new—to confuse the precise meaning attached to an equation of the kind:—

$$\tfrac{1}{2}S_2 = S_w$$

and to substitute *physical identity* for *numerical equality,* as shown by the above equation.

This cardinal error was the prime cause of the first "inflow" theories of the airscrew being inconsistent in their *formal presentation of the theory.* As a *method of calculation* they gave the same results as the correct and consistent theory of "inflow," because the *mathematics* of the subject were only concerned with certain equations such as the one given above, and, in both statements, the same equations might hold good.

It should now be clear how the confusion of thought commenced with regard to the original "inflow" theory of an airscrew. It lacked clearness in formal presentation, although the mathematics of the subject were sufficiently logical. This is proved at once by a reference to the formula deduced here for Ky, and a comparison with the original formula deduced by the author more than three years ago.*

Making identical assumptions in the two cases with regard to the value of λ, *i.e.*, taking $\lambda = 2$, the two formulæ become *identical.*

Yet the original paper of the author referred to above ("The Screw Propeller in Air") was illogical and inconsistent *in its formal presentation,* whilst the present paper does not suffer from this defect.

The author understands that certain authorities support the original "inflow" theory, whilst, on the other hand, others consider it to be inconsistent.

In the opinion of the author these respective standpoints are simply different points of view of the same thing, and the foregoing argument is intended to clear up any confusion of thought and to demonstrate that these two points of view are in reality precisely the same.

NOTE.—Since the above was written, Dr. de Bothezat's paper in the AËRONAUTICAL JOURNAL has been published in which he deals with the same subject. From a first rapid reading of Dr. de Bothezat's paper, it appears to the author that Dr. de Bothezat misunderstands the meaning attached by the English writers on the subject to certain words, such as "inflow velocity," and that a confusion of thought has arisen in consequence. The letters on this subject, in the December number of the AËRONAUTICAL JOURNAL, by Major A. R. Low and Mr. R. McKinnon Wood, suggest the same conclusion.

* "The Screw Propeller in Air," by M. A. S. Riach, Proc. Royal Aeronautical Society, March, 1917.

A CONTRIBUTION TO THE METEOROLOGY OF THE ENGLISH CHANNEL.

BY HUGH DUNCAN GRANT, F.R.A.S., F.R.G.S., F.R.MET.SOC., SUPERINTENDENT, NAVAL METEOROLOGICAL SERVICE.

The weather of the English Channel and South East Coast of England, like that of other localities in the British Islands, is well known to be variable and subject to rapid changes which take place sometimes with little or no warning. These changes are in places complicated by such factors as the general contour of the cliffs, an abrupt fall of the land towards the south, and the effects of evaporation taking place continuously over the channel, and giving such a well-defined local character to changes of wind as to mask temporarily the indications of an approaching disturbance.

Much, however, can be ascertained by the study of the local cloud formation, wind structure, type of barometric curve, and temperature variation, and the following discussion of certain aspects of Channel meteorology is intended to explain the commoner variations of weather which occur in that area. The meteorological peculiarities of the Channel may be conveniently studied under the six separate headings of atmospheric depressions (primary and secondary), winds, mist and fog, thunderstorms, squalls and gales.

1. ATMOSPHERIC DEPRESSIONS.

(a) Primary Depressions.—Among primary depressions are included the ordinary normal cyclone or atmospheric "depression" passing from the Atlantic across Ireland and pursuing an easterly course from Ireland to the North Sea. These present as a rule no difficulty to the local forecaster, and the Meteorological Office reports usually give sufficient warning of the approach of Atlantic depressions to allow necessary precautions to be taken. With such normal depressions moving from west to east, the following may be regarded as the weather sequence when the centre of the depression passes over the observer or north of him :—

Cirro-Nebula—a sheet of thin cloud giving rise to lunar or solar halo.

Cirrus Clouds (*Mare's Tail*)—usually about 12 hours before rain commences with motion from a point between N.W. and S.W.

Cirrus changing to Cirro-stratus—with a watery sun, or misty moon and solar or lunar halo. The fall of the barometer is now well defined, the temperature rises, and the wind backs.

Alto-Stratus Clouds—beginning to cover the sky from the west, and the weather becoming generally muggy and gloomy; about this time there is a slight periodic gustiness of the wind followed by a calm, or almost calm period, after which the steady increase of the wind commences, usually from the south-west.

Nimbus and Fracto-Nimbus Clouds—accompanying the increase of the wind, and fairly heavy rain. The fall of the barometer is now rapid, and these conditions continue until the approach of the "trough," when, provided that the depression has not passed too far to the north, there will be an increase of rain, generally known as the "clearing shower," and a veering of the wind to the west with a rising barometer.

Squalls—accompanied by the heavy showers, characteristic of the rear of a depression, the wind at times reaching a velocity of 60 or 70 miles per hour. If the depression passes well to the north of the observer,

the rear may bring wind only, with intervals of bright sunshine. The veering of the wind continues to the west and north-west followed by a gradual decrease of wind and a fall of temperature. Should the depression pass south of the observer the wind will back to the east and north-east, while its force will probably be less than in the above case.

During the comparative calm of the depression, while the barometer remains fairly steady, a dense cliff mist or fog will probably form.

Between the commencement of the formation of alto-stratus clouds and the moderating of the wind after the cyclone has passed, there may, in cases of moderate intensity, be an interval of nearly two days.

(b) Secondary Depressions, or small subsidiary areas of low pressure which accompany a primary depression, usually occur on its southern side, and give a stronger wind than the primary, with which they are associated.

The Channel about the Capel and Dover areas is peculiarly adapted to the formation of shallow secondary depressions, and sometimes the first intimation of these is the formation of rugged fracto-cumulus and cumulus clouds over the Channel.

Should the barometer rise rapidly, or give a jerky trace while the wind moderates somewhat suddenly from a speed of about 25 miles per hour, it is probable that a "secondary" is forming. From the aviator's point of view, special vigilance should be kept during this calm and bright period, as the secondary disturbance will come on with little or no additional warning, and the wind will increase again in a few hours probably to 20 or 30 miles per hour before the barometer has fallen appreciably.

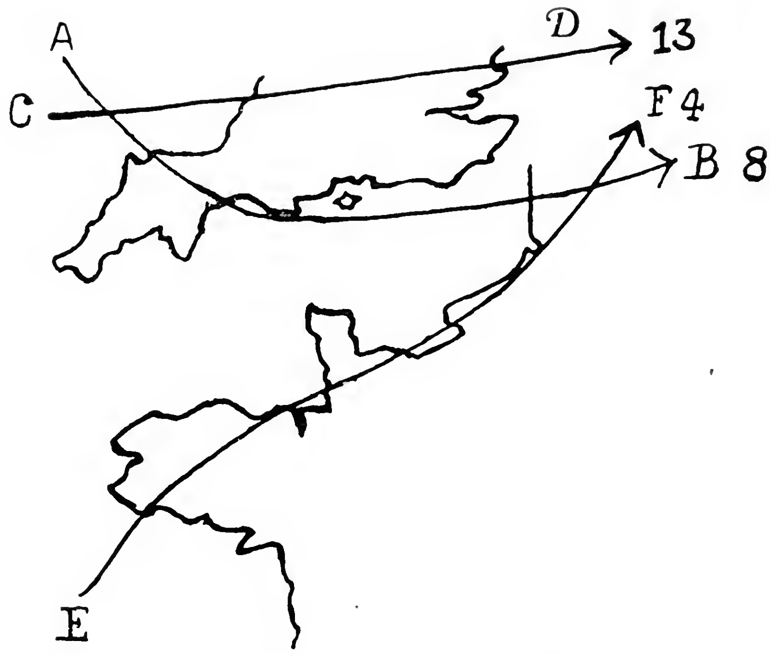
Generally speaking, any erratic movement of the barometer, however slight, if coupled with a squally trace on the anemometer chart, or even with a sudden decrease of wind velocity, should be taken as a warning of an approaching secondary disturbance.

The character of sunrise, and, to a less extent, that of sunset are useful in prognostication, especially in relation to secondary depressions. A red sunrise generally presages increased wind velocities.

(c) Movements of Depressions.—If the tracks of cyclone systems and their effect on the English Channel be studied in connection with Western Europe as a whole, it will be found that most depressions over France, Flanders and the southern side of the Channel are Atlantic depressions which have originated sufficiently far south in the Atlantic to touch the northern part of Spain. Pursuing their course from south-west to north-east, these depressions follow the English Channel and pass thereafter across Flanders into the North Sea, ultimately reaching Scandinavia. They have considerable influence over the weather experienced along the entire South Coast of England. It is notable that most of our depressions travel in the same directions as the anti-trade winds circulating on the Polar sides of the trade winds, namely in a north-easterly or south-easterly direction, and that they appear therefore to constitute turbulent irregularities of the main winds. The few depressions which have their origin over France or Flanders usually move due eastward without seriously affecting our weather. At times they cause on our shores northerly breezes sufficiently fresh to prevent the flying of airships, but rarely strong enough to exceed the flying capabilities of an aeroplane.

On the northern side of the Channel there is a well-defined cyclonic track, A—B (on map) intersecting another track, C—D, which more nearly follows the waters of the Channel off the south coast of Ireland. Another track is that indicated by the line E—F, which lies still further south along the coast of

France. The track C—D has, during recent years, more depressions lying to its account than A—B, which passes more directly along the northern side of the English Channel and causes the severest weather experienced on our southern shores.



In 1909 eight depressions followed the track A—B, and thirteen followed the track C—D. Along E—F, on the French side of the Channel, crossing Flanders, passing into the North Sea in a north-easterly direction and skirting the northern shores of Denmark, there were four depressions.

In forecasting south coast weather an interesting problem not infrequently occurs when a depression is centred off the south-east of Ireland, about the point where A—B and C—D intersect, and the question arises whether it will pursue the southerly or the more northerly path. In other words, whether the wind will "back" or "veer" in consequence of the path of the depression being to the north or south of the observer.

(d) Cumulus Clouds on the Southern Horizon in relation to Atlantic Depressions.—The approach of an Atlantic depression may often be detected 24 or more hours before its announcement by the Meteorological Office. This may be done by observing in advance of such a depression the gradual development of a long line of well defined cumulus clouds, which invariably appears on the southern horizon over the French coast. In cases where the depression is considerably to the north, the clouds are fine in detail and become larger and more rugged as the depression passes further south, but, unfortunately, they are visible only in clear weather.

Should the depression be located to the south of Ireland, the cloud formation will be nearer but will still partake of the cumulus type just described. In cases when the depression ultimately passes to the north of Ireland, and across the north of Scotland, these cumulus clouds, as seen from the south Kentish coast, have an altitude of about 1½ degrees, and this altitude increases to about 4 degrees when any depression crosses Central Ireland and Northern or Central England. As the depression approaches, they increase in size, but become obscured owing to poor visibility.

In a few cases where the cumulus formation has been observed, the depression has failed to cross the British Isles, but this may be explained by the dispersal of the Atlantic disturbance or its passing away north.

With a west wind the height of Channel cumulus clouds may fall to the level of the cliff, which at Beachy Head is 505 feet above sea level. As a rule, however, they pass at a height of 100 to 150 feet above the cliff or 600 to 650 feet above mean sea level.

Another frequent precursor of a depression is a mass of low cloud, popularly termed "scud," which may be seen approaching Beachy Head from the west. On arriving at the Head the clouds appear as a mist enveloping the entire surroundings. In due course they form into cumulus or strato-cumulus suggesting that in this instance cumulus clouds may be caused by moist air being driven upwards towards the cliff edge.

2. WINDS.

An exhaustive investigation of this subject would call for observation extending over many years, but the following peculiarities in the behaviour of local winds were ascertained from a careful study during a period of scarcely more than one year.

When the pressure gradient is favourable for light winds from between north-east and east, local temperature should be carefully watched, observing that a sharp fall of temperature throughout the night, followed by a clear morning and rapid increase of temperature, usually indicates a freshening of the wind to 20 or 30 miles per hour during the morning, moderating after 3 p.m. This morning wind is generally very gusty and may cause in their present stage of development considerable difficulty to airships in landing.

When pressure is relatively low over France, northerly winds may, at times, exceed the forecasted strength, but on the other hand, if the weather is bright, there may be, owing to local "sea breeze" tendencies, a temporary moderation of the wind about mid-day with a return to normal velocity later in the afternoon.

(a) Wind in Mid-Channel.—The wind circulation observed in Mid-Channel usually differs from that prevailing on land. When light and variable on land, the wind is also light and variable in the Channel, but when moderate or fairly strong (Beaufort Force 4-5) on land, it invariably veers in Mid-Channel, increasing appreciably in speed. Pilots engaged in patrolling the Channel from Capel Airship Station were agreed that the extent of the veer in Mid-Channel might be regarded as approximately two points of the compass or 22 degrees. It was found on several occasions that with a westerly wind from 15 to 25 miles per hour on land, a wind from W.N.W. (of similar velocity) prevailed in the Channel.

Since making the first observations at Capel Royal Naval Airship Station, the writer has had an opportunity of making similar observations while travelling by airship along that portion of the Channel lying between Eastbourne and the Isle of Wight, covering a distance of 110 miles over sea and 21 miles over land.

These observations confirm the previous indications regarding the local winds peculiar to the Channel, viz.:—

1. That in Mid-Channel there prevails a slightly different wind circulation to that observed over the land.
2. That, when light and variable on land, the wind is also light and variable in Channel, but, when moderate or fairly strong (Beaufort Force 4-5) on land, it invariably veers 22 degrees in Mid-Channel.

Such peculiarities may be due partly to convection and eddy friction and partly to cliff eddy effects, but so far as the latter are concerned, the explanation is questionable as the eddies caused by a wind of less than 20 miles per hour scarcely extend to more than one mile seaward from the cliff edge. With very light winds no appreciable eddies are formed, but on the other hand, the Mid-Channel winds become more variable in direction with decreased wind velocities. As one flies

down-Channel towards the open sea, say to a point 35 miles south of the Isle of Wight, these features are not so pronounced, but nearer to Folkestone and Dover they are more noticeable. This seems to indicate the importance of the land configuration and contour of the cliffs generally on both sides of the Channel, as also the steep slope of the land towards the sea along our south-east coast line, in relation to the entire wind circulation and weather in Mid-Channel. Another important factor may be the evaporation during periods of calm under a clear, or comparatively clear sky with bright sunshine.

The land configuration on both sides would appear to encourage variations from the normal, and especially favour the formation of shallow depressions. As a matter of common experience "secondaries" frequently occur in the Channel, bringing heavier rain and more unsettled weather than are caused by their parent "primaries."

They also, as a rule, travel rapidly, the passage of the trough being marked by a line squall.* The rain associated with them falls generally in brisk sharp showers, followed by drizzle. Should the secondary be of considerable energy, its approach is frequently heralded by a red sunrise or by a line of cumulus cloud over the French Coast coupled with a period of extreme visibility as described in connection with the main depression. During this period, the Isle of Wight, some 62 miles distant, may be seen from Beachy Head, and the French coast from Capel Aerodrome.

(b) Coastal and Inland Winds from Airship Observation.—In consequence of frictional effects, land winds are not, for the same barometric gradient, so strong as sea winds. It is therefore not surprising to find that the average wind velocities at Capel and along the adjacent coast line should exceed those prevailing a few miles inland. A striking example of this was observed by the writer during a cross-country flight from Capel Aerodrome on March 16, 1917. At the aerodrome a wind of 17 to 18 miles per hour from S.S.W. was recorded, whereas, at a short distance inland, it was under 10 miles per hour throughout the entire journey from Dover to Tunbridge Wells via Folkestone and back again to Capel Aerodrome—altogether 140 miles. The flight commenced at 9.50 a.m. (G.M.T.) and lasted four hours, namely from 9.50 a.m. to 1.50 p.m. (G.M.T.). The height of the airship when crossing the edge of Dover cliffs was approximately 1,400ft., or 1,900ft. above mean sea level. It was found necessary with a wind of 15 to 20 miles per hour to fly at considerably over a thousand feet in order to minimise the effect of the "downward dunt" experienced on crossing the cliff edge from land to sea. This is true with any wind blowing either "on" or "off" the cliffs. With a surface wind of 10 to 15 miles per hour, the airship pilots when over the Channel generally flew at heights from 300 to 900 feet.

The general distribution of pressure at the time of the flight was anti-cyclonic over the Channel, with a low pressure area off the north-west coast of Scotland, producing strong winds in the west and north-west of the British Isles, and as far south as Anglesey, with unsettled weather everywhere except in the extreme south.

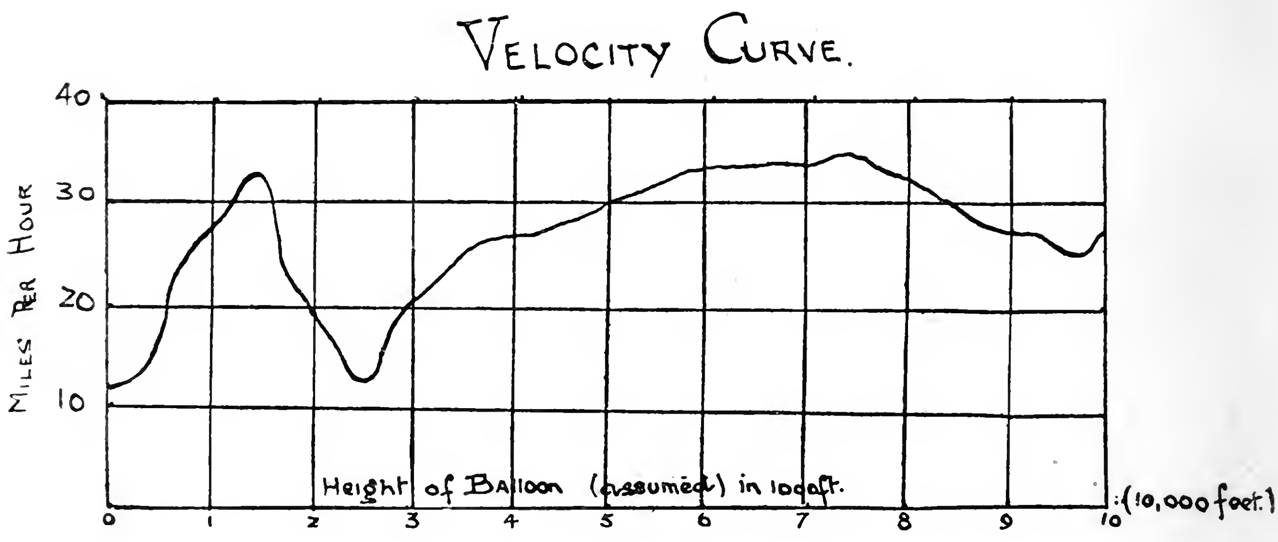
At the time of the ascent the surface wind at the Capel Aerodrome was S.S.W. 17-18 miles per hour. Inland, as stated, the wind was appreciably less. At Tunbridge Wells and within a radius of 4-5 miles of the coast line, it was not more than 10 miles per hour.

(c) Channel and Cliff Eddies.—On some days when the wind was fairly steady on land, as shown by pilot balloon flights, airship pilots flying in Mid-Channel have

* A squall of wind, accompanied by rain or hail, associated with a sudden drop of temperature and the passage of a long line or arch of dark cloud. The cloud appears to be due to convection between the cold westerly currents and a warmer southerly current; the squall is therefore probably katabatic in its origin, and its violence on the the actual passing of the cloud accounted for in that way; it represents the dash forward of a breaking wave, or, more strictly speaking, of the water of a broken wave. (See Section 5 of this article.)

observed extreme "bumpiness" (*i.e.*, sudden upward or downward motions caused by patches or pockets of air of different densities). Bumps are mostly due to rising currents of air over surfaces that are at different temperatures, and to eddy motions caused by irregularities of the surface. They also occur at the cloud layer when there is a sheet of cloud, and they occur almost invariably with cumulus clouds. Over the cliff edge with a northerly wind, there are usually severe downward currents. This is true more particularly along the cliff edge between Dover and Folkestone, the "bumpiness" being felt when an airship is in the act of crossing the cliff edge either on its way to or from a Channel patrol.

It may be mentioned that a pilot balloon flight is a convenient means of estimating the speed and direction of the upper wind, a pilot balloon being a small rubber balloon inflated with hydrogen to such an extent as to give it an approximately uniform rate of ascent. The balloon is liberated and followed during its flight by an observer using a theodolite. From the azimuth and altitude angles of the balloon observed during the time it remains in sight, the direction and speed of the wind at various heights can be computed by assuming that its rate of ascent is constant. When these ascents are made along the Channel coast line during winds from points between north-west and north-east the balloon is generally caught in the downward current over the cliff edge, and allowance must be made for this by balancing the worked out velocities. In complicated or uncertain cases, the plotting of the ascent graphically may help to eliminate the error as in the following example, in which the prevailing wind is from a northerly direction.

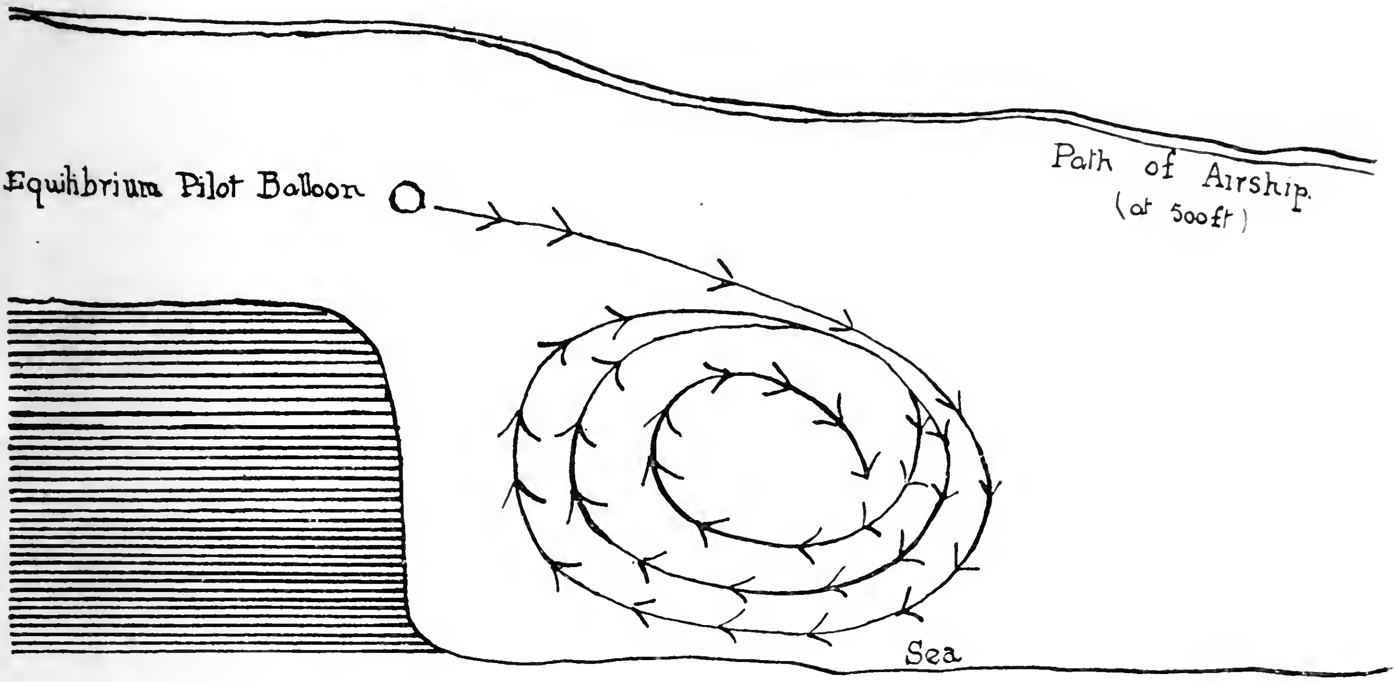


During east winds, especially when the sky is overcast with large masses of cumulus clouds, the wind velocities, as given by the single observation pilot balloon method, will generally be too low. This is owing to the strong up-currents usually existing. Test balloons with a slight negative buoyancy have been known to rise at least 5,000ft. per minute during above conditions.

Equilibrium balloons (*i.e.*, small rubber balloons used for pilot balloon ascents, inflated with hydrogen only to the extent of enabling them to remain in equilibrium in still air without any tendency to rise or fall) liberated from the cliff edge during northerly winds were immediately caught in the eddies and carried in the circular path denoted by arrows in the following diagram.

The line indicates the path of the airship and the downward curve in the trace explains the "bumpiness" experienced on crossing the eddy and cliff edge.

Each time the balloon returned to the cliff edge it was driven outwards again until in the end it had described a series of closed curves. It continued to describe



these circles until, carried by the eddy along the coast, it ultimately burst. The airship crossing the eddy at 1,500ft. above the cliff edge merely experienced the downward current. The higher the airship ascended the less severe was the downward "dunt" or sudden decrease in altitude of the vessel.

The upward current from the water some 500 feet below meeting a contrary land breeze and the consequent return suction of the air may probably be the explanation of these eddies.

With regard to the probable distance on either side covered by the stream of eddies in the case of a wind blowing "on" or "off" the cliff, it is noticeable with a south-west and west wind of 20 miles per hour that a pilot balloon with the rate of ascent of 500 feet per minute is affected for three or four minutes from the moment it gets in touch with the cliff eddies, appreciable increase in the mileage occurring during the first and second minute. The balloon becomes more steady the farther it proceeds from the cliff edge. This would point to the following phenomena :—

(1) With a wind of 20 m.p.h. blowing "on" or "off" the cliff, the string of eddies extends for about one mile from the cliff edge.

(2) The greater the surface wind velocity, the longer or more numerous the string of eddies, and vice-versa, in proportion probably to this rule of one mile for a surface wind of 20 m.p.h.

(3) With very light winds no appreciable eddy is formed.

(4) The farther from the cliff edge, the less the turbulent motion becomes, and consequently the smaller the eddy.

(5) The most vigorous eddy is invariably at the cliff edge, the size and force depending upon :—
   1. The velocity of the surface wind.
   2. Height of cliff above mean sea level.

(6) The above applies to a wind blowing either hard "on" or "off" the cliff.

In the case of a wind blowing "on" the cliff, it is difficult sometimes to say whether the "bumpiness" experienced by an airship near the cliff edge is really due to the existence of an inland cliff eddy there—especially if within a radius of one mile from the sea—or to vertical currents caused by the configuration of the

land generally. In this connection it might be interesting to note the appreciable difference between the wind velocity recorded at Beachy Head and that experienced at Polegate Airship Station on August 22nd, 1917. The anemometer at Beachy Head Meteorological Station on that day recorded a wind from S.S.E. of nine miles per hour; at the same time, only five miles distant and in the vicinity of Polegate Aerodrome, a surface wind of from 24 to 26 miles per hour was observed. The anomaly may be due to the S.S.E. wind on striking Beachy Head rising vertically, causing a rarefaction of the atmosphere on the Head itself, and an increased, if not doubled, velocity at Polegate.

The circular path of the eddies, as denoted by an equilibrium pilot balloon liberated from the cliff edge, may be further illustrated by the accompanying photographs taken at Beachy Head on July 26th, 1917.

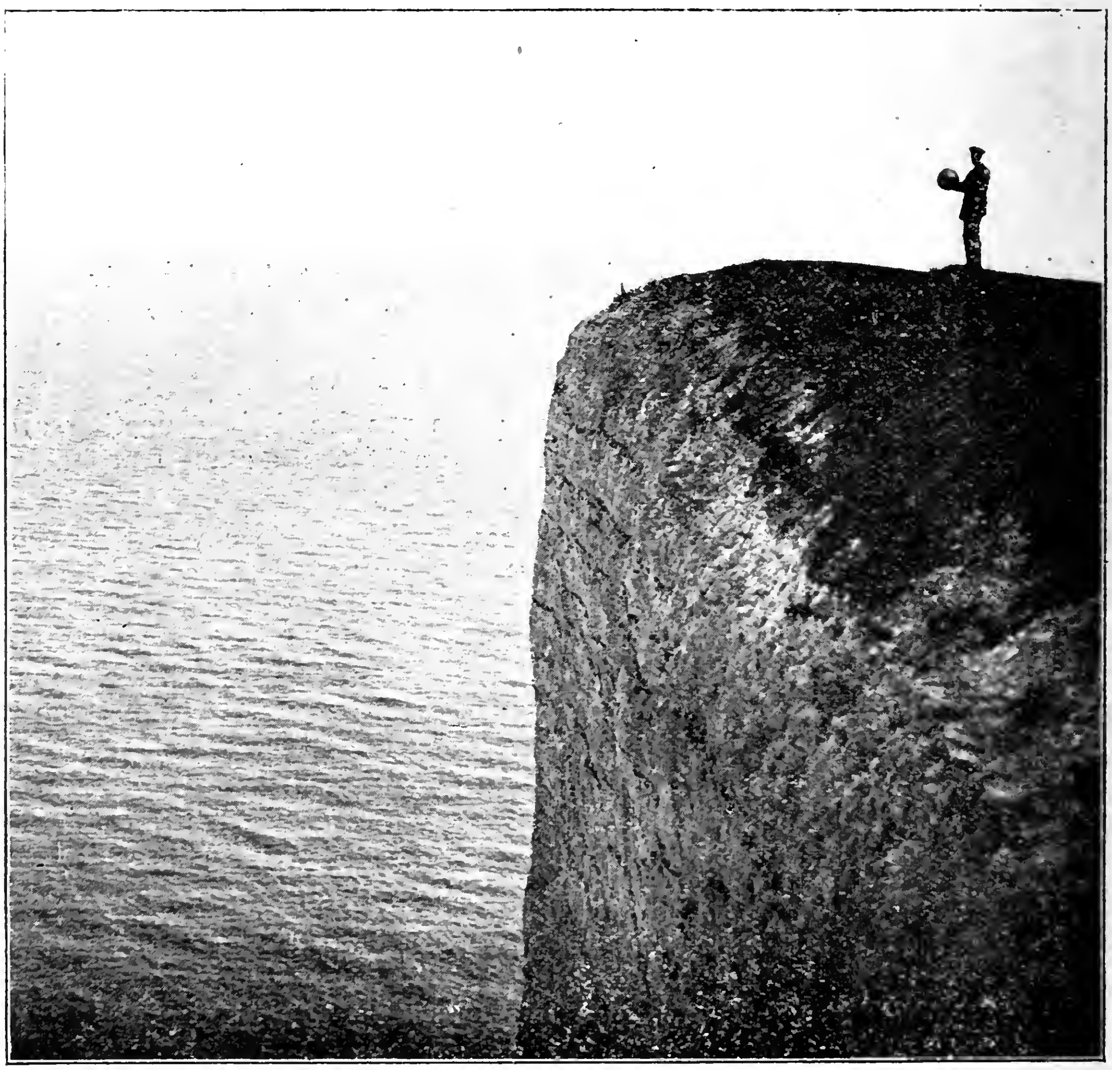


Fig. 1.

Fig. 1.—Shows the formation of the cliff and the equilibrium pilot balloon in the act of being liberated.

Fig. 2.—Shows the balloon caught in the cliff eddy and about to descend in a circular path towards the sea 500 feet below.

Fig. 3.—Shows the balloon carried back by the force of the eddy towards the cliff, after describing an almost complete circle, to within seven or eight feet of the sea. It will be observed about six feet from the middle of the cliff.

The surface wind at the time of liberating the balloon was W.S.W. 13-19 miles per hour, and the wind at 1,500 feet, as ascertained from a quick free-lift pilot balloon, was W.S.W. 17 miles per hour.

Matters requiring further investigation are :—

(1) Surface speed and direction of cliff eddies.

(2) Height at which aircraft just misses the downward "dunt" referred to.

(3) Height to which cliff mist extends.

(4) Distance to which it extends inland from cliff edge and to east and west.

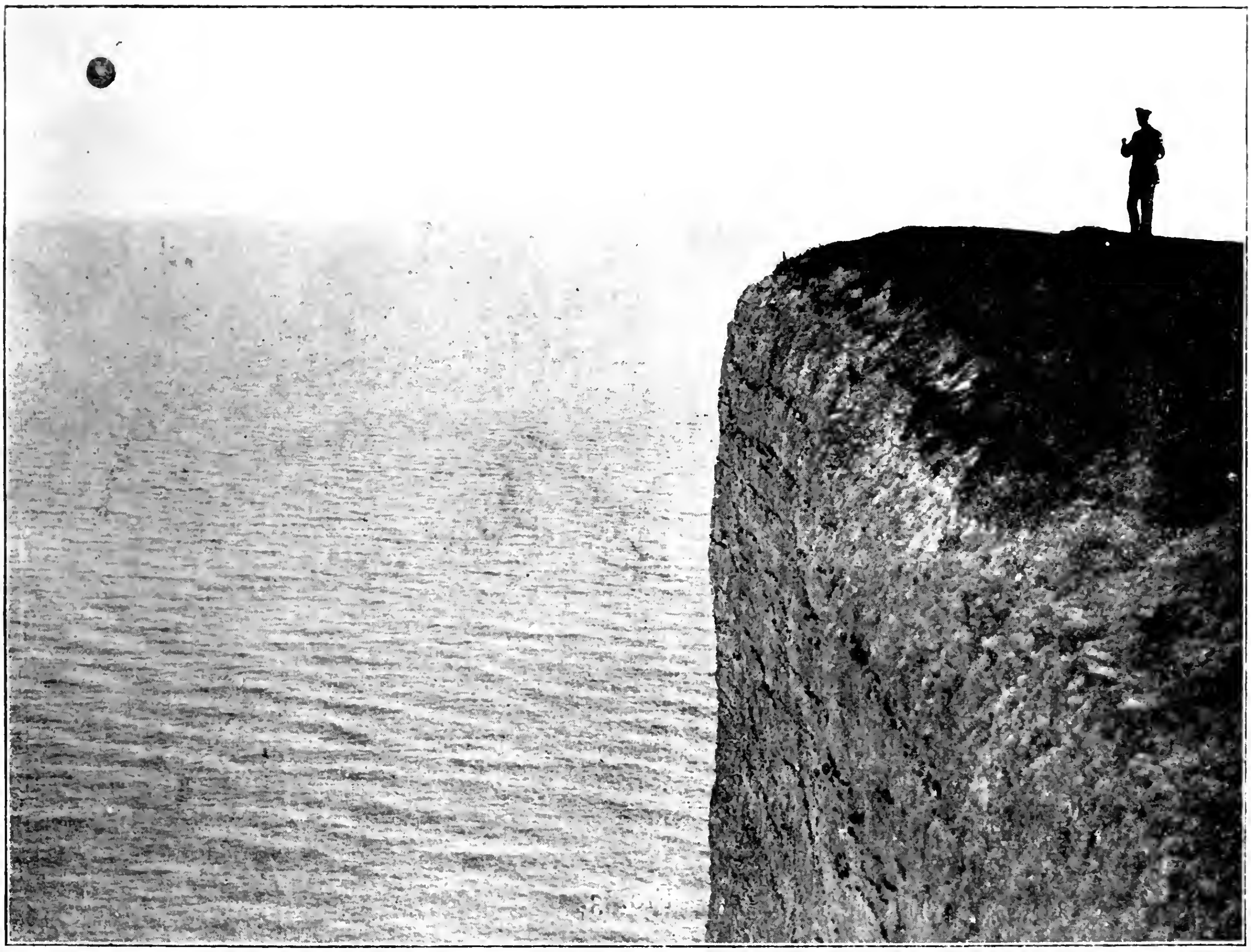


FIG. 2.

III. MIST AND FOG.

During anti-cyclonic conditions the weather in the South-East of England is frequently misty. Inland mist, and at times drizzling rain, occur during the periods of slight north-westerly or north-easterly wind gradients, and local cliff mist may form with the diurnal change of the wind to south-west. Variations of cliff mist (increase or decrease) usually occur about 10 a.m. noon or 4 p.m.

Channel fog (sea fog or mist) occurs especially during light easterly winds, the mixing of the warm moist air with the colder layers causing a dense fog, which usually forms a bank, sometimes as much as 200 or 300 feet in depth.

The occurrence of cliff mist is necessarily difficult to forecast with a degree of certainty peculiar to that of other meteorological elements, but, as a general rule, it may be noted as occurring :—

1. With a steady or slightly rising barometer (seldom with barometer falling slightly).
2. With a south-west wind of velocity 10-25 m.p.h.
3. With relative atmospheric humidity of 90 per cent. or above.

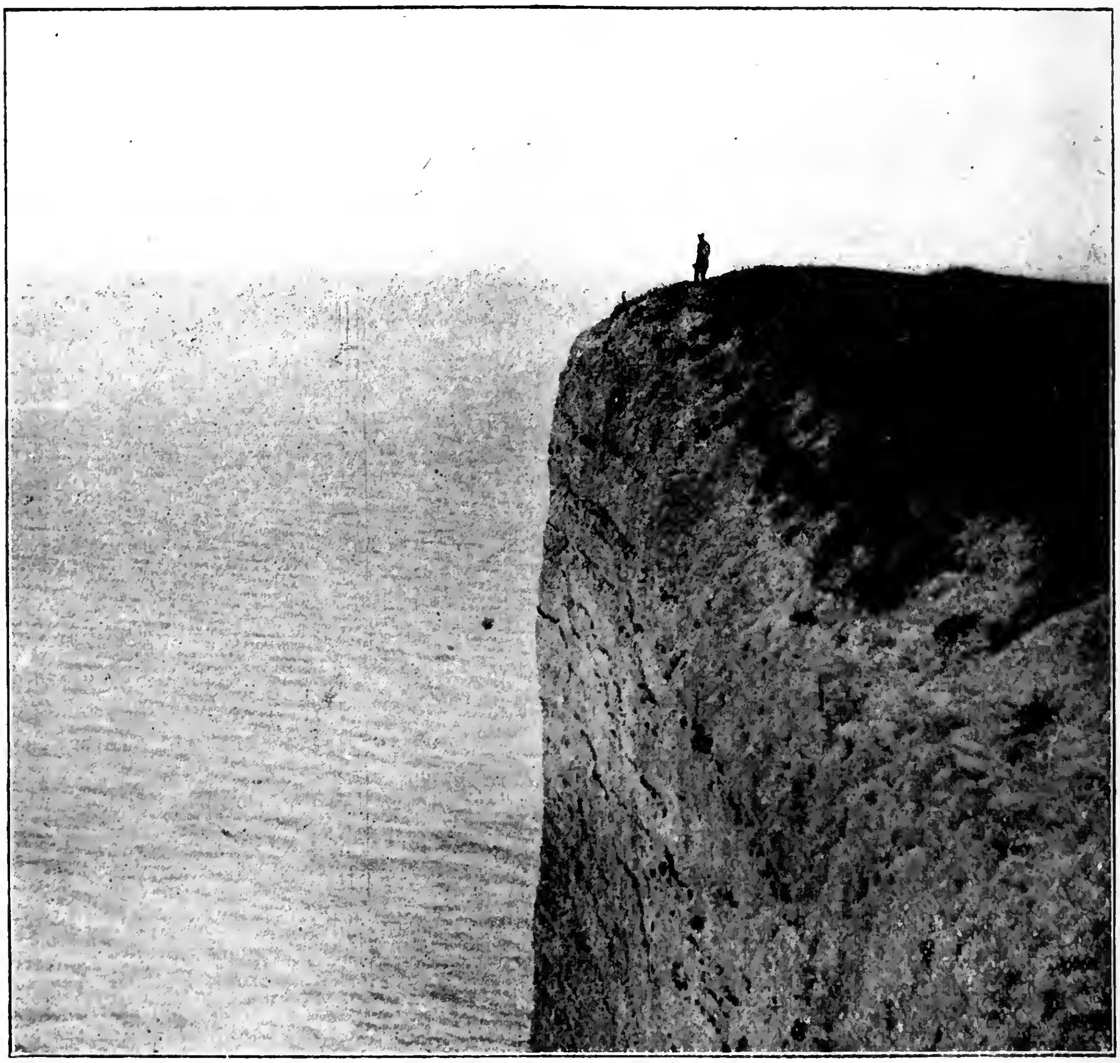
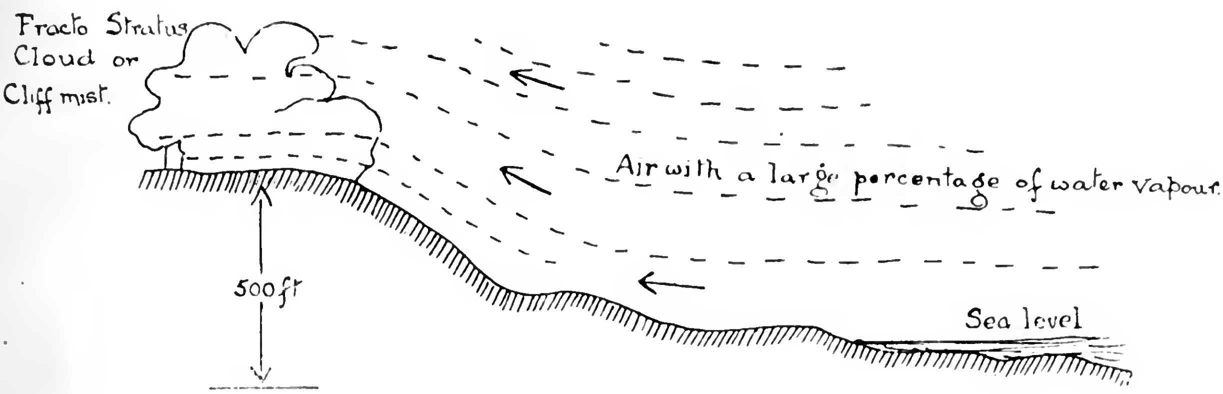


FIG. 3.

At any time when the foregoing conditions exist simultaneously, cliff mist may form whether the pressure distribution be cyclonic or anti-cyclonic. The local cliff mist on the South Kentish coast is mainly caused by the upward deflection of the moisture-laden south-west wind over the face of the cliff. This air in rising is cooled adiabatically in consequence of being relieved of a portion of its pressure, and as a result local condensation follows. At times this moist air current may rise to about 600 feet above sea level (that is, to about 100 feet or more above the cliff) before condensation occurs, in which case, as the following diagram may help to show, it develops into a cloud of the fracto-stratus type.

Cliff mist is thus probably caused by an upward current of air from the water surface cooling and condensing its moisture at the cliff edge. There can be little interaction with a land current because of the surface wind being from S. to S.W., and therefore in effect a sea to land current. Observation has shown that if the



surface wind be below 10 miles per hour it is not sufficiently strong to cause the upward current to ascend to the cliff top, and therefore there can be no condensation or cliff mist. On the other hand, if the wind be above 25 miles per hour, the upward current is generally carried to cloud height (say 1,000 to 1,500 feet) before condensation appears to take place. It is then evident in the form of stratus (fog) cloud.

During certain types of anti-cyclonic weather when cliff mist or fog occurs with frequency and persists for days at a time, cross-Channel flying is much hindered. This was particularly true during the period of these observations. During winter, fog or mist not infrequently mars the anti-cyclonic interval between two depressions. With prolonged periods of calm weather there is sometimes a haze over the Channel, making it impossible to observe objects on the water surface from a height of 4,000 to 5,000 feet.

In order to complete this brief investigation and to provide data for a more elaborate discussion, it is proposed that the following observations should be carried out at the Meteorological Station, Beachy Head, during a typical occurrence of cliff mist, and they will form, it is hoped, the subject of a later paper, viz.:

(*a*) Humidity of air at sea level.
(*b*) Temperature of air at sea level and below the mist.
(*c*) Temperature of the water in relation to that of the air:—
    1. Away from the cliff at Beachy Head.
    2. Below the cliff.
(*d*) Temperature of the air below the cliff.

IV. THUNDERSTORMS.

During the usual thunderstorm periods of the year, *i.e.*, during the summer, the Channel region appears to suffer more from electrical disturbance than the other British coasts. As elsewhere, there is a pronounced tendency for electrical storms to occur during the afternoon and evening hours.

When the southern half of England, and especially the south-east counties, are situated in that somewhat peculiar but not uncommon distribution of pressure known as a "Col" between two anti-cyclones, or in a "Saddle Back," thunderstorms occur in the Channel. A typical instance of such a distribution is a low area in the Mediterranean between Italy and Spain, a belt of high pressure spreading along the coast of Spain from the Azores to the Atlantic with a large shallow or a moderate depression slightly to the westward of the British Isles. Associated with this barometric distribution a severe thunderstorm with heavy rainfall in places occurred in the London district, Northern France, and along the Channel (from Portland Bill to the Isle of Grain) on the evening of September 5th, 1917. Thunder squalls in the Channel are also frequently associated with secondaries which may have formed in the mouth of the Channel in the rear of an

Atlantic depression, or with a primary situated off our western seaboard. In winter thunderstorms in the Channel are almost entirely of the line-squall type. The tendency to thunder is usually predicted with a considerable degree of accuracy in the reports of the Meteorological Office, but earlier and unmistakable indications are generally to be found locally from such occurrences as a contrary movement of different layers of cloud, the formation of heavy cumulo-nimbus cloud, and an unusually calm or oppressive atmosphere. Cumulo-nimbus, the true shower cloud, from which rain, hail, or snow is falling, may be distinguished from simple cumulus by the fact that the top of the former cloud, instead of being rounded and hard-edged, is brushed out into a soft-looking mass of fibrous cloud called false-cirrus. Cumulus-nimbus are often thus to be seen in isolated masses, some miles in circumference perhaps, and are the seat of very rapidly ascending currents of air making their presence a source of danger to the aviator. They usually begin to form in the morning as the day gets warm, and reach their greatest development about two or three in the afternoon, after which they generally begin to disappear and by sunset or soon after the sky may be quite clear even after a day of great development of this form of cloud. But they may be met with at other times, and they form after sunset in the summer when, as stated, shallow depressions bringing thunderstorms are approaching.

A wireless receiving set is a valuable adjunct to the means of obtaining information of an impending thunderstorm. The lightning recorder also gives useful assistance, but owing to the present imperfect state of development of this instrument too much reliance should not be placed upon the records obtained. It may be observed, from the point of view of the aviator, that the greatest danger from thunderstorms in airship work arises from wind squalls, and in the heavy rain and hail that accompany them. There is also the danger of an airship becoming highly charged during thundery conditions causing the hydrogen to ignite, and it would appear advisable, for this reason, to wind in the wireless aerial, and keep as far from all clouds as possible; in fact, fly low and fairly close to the sea level. If close to a highly-charged cloud it is probable that the exhaust gases from the motor may allow the electricity of the same sign as the cloud to dissipate itself, and consequently result in the increase of the potential difference existing between the cloud and the ship.

These conditions whether over sea or land are obviously favourable for the sudden discharge of electricity by spark, either between the cloud and the ship, or perhaps between the ship and the ground when landing. There are several cases on record in which meteorological kites have been struck by lightning, and as some of these occurred when there was no thunderstorm in progress, it must be remembered that clouds may be highly charged with electricity at times when no actual storm is going on.

V. SQUALLS.

Reference has already been made to thunder-squalls in the Channel. A squall is a temporary rise in the wind above the mean velocity that precedes and follows it, the rise in velocity being continued over some minutes at least, and is thus distinguished from a gust which lasts only a small part of a minute. Squalls are of innumerable degrees of severity. In the Channel on a day of blustery north-west winds when there are large cumulus clouds about, one may have a succession of squalls, whose approach can be seen at sea some time before their onset. Such squalls are probably not of any particular danger to aeroplanes as at sea they are not of much danger to shipping, except in the case of small open sailing boats, but at seaside resorts they take their toll of holiday-makers who are sailing with the main-sheet made fast.

More intense squalls are associated with thunderstorms and they are all the more dangerous since they are often preceded by very light winds or even by a

complete calm, and within a few minutes from their onset the wind may increase to a speed of even 60 to 80 miles per hour. A typical example of such a squall which was also experienced in the English Channel was reported by Captain C. J. P. Cave, R.E., in a paper read before the Royal Society of Arts on May 2nd, 1917. The following is an extract:—"As seen in the east of Hampshire, this storm came up from the direction of the Isle of Wight in the shape of a huge cumulus cloud with a great extension of false-cirrus at the top, giving it the appearance of a giant mushroom; the day had been very hot and the air was very still. As the storm approached it was seen that heavy rain was falling, but there was no sign of wind to the untrained eye. A few minutes before the rain reached the observer a continuous roar was heard, and as the first drop fell, a furious blast of wind arose; the wind only lasted a few moments, and in three-quarters of an hour the storm had passed and the weather was fine again. The storm passed over the South Downs, and the same storm or another moving parallel to it reached Guildford, where the damage done by the wind was very great." The squall in front of an ordinary thunderstorm is probably a modification of another variety known as the line-squall. The sequence of events in a line-squall is somewhat as follows:—A bank of clouds is seen extending along the horizon, the upper part being white and in shape like ordinary cumulus, though the whole cloud usually appears of a more uniform height, and not broken up into such distinct peaks as in ordinary cumulus. As the cloud approaches it is seen to be extremely dark below, and it usually extends in a long line stretching from horizon to horizon, but owing to the effect of perspective it appears like an arch in the sky, the summit of the arch coming nearer and nearer overhead. As the cloud reaches the observer a violent squall springs up, the wind veers rapidly or even suddenly, rain falls in torrents and is often accompanied by hail, and there may be thunder and lightning; at the same time the temperature falls considerably, a fall of five or ten degrees being common, and it is sometimes as much as twenty degrees. When the cloud is approaching and is nearly overhead a curious sinuous line is seen at its base extending right along the front of the cloud, and it is this line which gives the name of line-squall to this disturbance. After the first blast the wind blows strongly for a time and the rain lasts for half an hour, more or less; this is followed by a less intense fall of rain and by decreasing wind, and after an hour or so the weather often clears up and becomes fine.

A line-squall is only a few miles across, but it may be several hundred miles long and it advances across the country broadside-on at the rate of twenty to forty miles per hour; one such squall has been traced from Cape Wrath to the centre of Germany. The list of disasters caused by the line-squalls is a long one; the best known case is that of H.M.S. "Eurydice," a training ship homeward bound that was struck by such a squall when off the Isle of Wight on March 24th, 1878, and foundered with heavy loss of life.

In addition to the blast of wind in front of the squall, there are great up-currents in front and down-currents near the middle of the squall, with much eddy motion between them. From the aviator's point of view, such conditions can hardly fail to be dangerous, and though an aeroplane may possibly come safely through them, it is hardly likely that an airship would.

VI. GALES.

In the Channel, gales frequently spring up with great suddenness at all times of the year; in fact, a sudden gale, and especially an easterly summer gale, often gives less warning of its approach than a winter one. Anyone who has done any sailing round our coasts must remember cases when they have been caught in gales a couple of hours or so after having been lying becalmed.

CONCLUSION.

In the opinion of the writer, no portion of the seas adjacent to the British Isles presents a more interesting and promising field for the pursuit of meteorological research than the English Channel. Associated as it is with the weather distribution over the Continent and the North Atlantic, it presents an excellent blend of continental and oceanic weather conditions.

The majority of migratory areas of low and high barometer experienced in Southern England and along the Northern Continental seaboard either cross the Channel directly or skirt it indirectly at some point or other. Again, not a few depressions originating in the Eastern Atlantic during the months of stormy trades may be felt, eight to ten months later, in or in the neighbourhood of the English Channel. The seasonal frequency of thunderstorms is greater in the Channel than in any part of the United Kingdom or elsewhere in the waters surrounding the British Isles.

The Channel presents unrivalled opportunities for the study of effect of contours, and of the distribution of land and water, on local weather. The relatively large number of well-equipped observatories on both sides of it, combined with the density of population on the coasts and the great amount of Channel traffic, resulting in a host of voluntary observers, render available a considerable mass of material for the intensive study of any one phenomenon, facilities of which Mr. J. G. Fairgrieve has made full use in his studies of rainfields and thunderstorms. The variety of weather in this region and the rapidity of its changes must always excite the interest of meteorological students, while at the same time it affords the strictest test of prognostics.

The frequent origin of thunderstorms in the Channel is a matter deserving of special attention and one to which the captains of ships travelling these waters might contribute useful observations. A large number of the accidents to small sailing boats, especially pleasure boats, is due to thunderstorm squalls, and the mode of origin of the small secondaries causing these storms requires careful study. Such study must depend on observations made from ships in the Channel, especially at the western end, where the disturbances appear often to form.

REVIEWS.

Design of Aeroplane Engines. By John Wallace. London: Benn Brothers, Ltd. 15s. net.

This book is based upon a series of articles contributed by the author to "Aeronautics" in 1918-19. In his introduction, Mr. Wallace states that he has "endeavoured to explain as clearly as possible the fundamental principles underlying the general and detail design of the modern high-performance aeroplane engine," and he has succeeded to the extent of producing a practical primer which is well written and well arranged, but is by no means comprehensive.

The book should prove useful to students, draughtsmen, and mechanics, but of little value to good aeroplane-engine designers as the treatment is too superficial and elementary to meet the needs of those who are already acquainted with aeroplane engine development. In a book of this kind one often finds things which are very wide of the mark, and the reader should satisfy himself as to the correctness of the statements made and the soundness of the opinions expressed. Thus on page 15 the weights of corresponding rotary and radial engines are compared in a manner which leaves entirely out of account two important factors, namely, that radial engines require balance weights, whereas rotary engines do not, and that the stresses and bearing loadings are entirely different for the two types. Again, in a statement respecting cooling systems, which is given at the bottom of page 19, the author slurs over the important fact that one has to maintain a sufficient rate of water circulation through the engine and radiator in order that the temperature change between inlet and outlet shall not be excessive and thereby necessitate an unduly large radiator to obviate boiling troubles.

On page 25 it is stated that the mean effective pressure is the equivalent mean pressure acting on the piston throughout the cycle. This statement will confuse readers who are not already aware that mean effective pressure is reckoned on the working stroke alone, the other strokes being reckoned as idle strokes. The author declares that formula 2, given on page 26, is not exactly true for high-speed petrol engines—and yet the formula in question corresponds exactly with the correct definition of brake mean effective pressure! The treatment of brake mean effective pressure is further confused by calculations of mean effective crank effort which give results inconsistent with the brake mean effective pressure valve. Another example showing the need for the reader to do some reasoning on his own account may be taken from page 69, where an engine arrangement is shown which purports to balance out torque reaction—but of course, if the power is absorbed by a single propeller, the torque reaction on the engine as a whole must be equal and opposite to the torque transmitted through the propeller shaft to the propeller and to the air upon which it acts.

In spite of such blemishes there is much in the book that is readable and should help the student to bear in mind the various practical aspects of the subject when he proceeds to study more advanced technical works.

B. C. C.

Practical Aeroplane Construction. F. J. Hill. Spon. 12s. 6d.

In his introduction Mr. Hill offers what might be read as a half apology for this volume. We can assure him that nothing of the sort is needed.

He has set out to produce a handbook of aeroplane construction from the shop side, and the result is a work which we feel sure will be appreciated by the designer

and student alike. Design cannot consist solely of drawings produced in an office as the result of mathematical calculation—it is essential that the details shown on the drawings can be made, and made economically, in the shops.

Up to the present most of the books on aeroplane design have dealt with the theoretical side of the question, and when they have touched on practical construction, very little mention has been made of shop practice.

Mr. Hill avoids theoretical design problems and deals solely with practical methods of obtaining the goods. Starting with steelwork he describes the simpler methods of tube manipulation, welding and brazing processes, and then discusses press tools for the manufacture of plate fittings, etc. A chapter on the construction of tanks completes the metal work side of his book, and he then proceeds to describe briefly the work connected with the sawmill.

His chapter on detail construction in timber is good. Later chapters deal with assembling, airscrew construction and covering and doping.

The methods of inspection for aeroplane parts are discussed in detail, and this we think will prove of special interest. The concluding chapter is devoted to erecting and rigging.

A feature of the volume calling for special commendation is the illustrating. This is extraordinarily good, and considerable skill has been shown in the preparation of the drawings.

Altogether this is a very practical, useful and readable book.

Commercial Airships. By H. B. Pratt, M.I.N.A. Nelson. 15s.

It appears that this book is not, as might be hoped, intended to form a contribution to the technical side of the airship question. It is written by Mr. Pratt, the chief engineer of the airship department of Messrs. Vickers, Limited, and it is difficult to reconcile a very great number of the views and statements in the book with authorship by one in such a distinguished technical position.

One fundamental mistake which prejudices the whole book is that the author makes no distinction in his wording between achieved fact and what he imagines will take place in future, *e.g.*, p. 77 :—

"The airship is then moved out of the shed by running two propellers astern (rigid airships are preferably moved out stern first). When sufficiently clear of the shed, all engines are started, ballast is dropped, the guys are cast off and the ship ascends."

There are several historical mistakes and omissions. From the story of the various classes of ship built in England, R.31 and R.32, the two rigid ships built by Messrs. Short Bros., of which the latter was so successful as regards speed, are altogether omitted. Reference is made to the longest patrols of the Service-built N.S. airships as of 50 hours. Their record flight was just over 100 hours, and has recently been accepted by the F.A.I. as the world's airship record. He refers to the mooring-out shelters for small airships, the very wide use of which by our airship officers constituted such a very fine achievement, as "Such as were used for kite balloons and small airships in France."

Many of his figures for achieved results are very optimistic. The disposable lift of R.34 is given as 50 per cent. of her gross lift. The correct figure is 40 per cent.

Estimated figures are also very optimistic, *e.g.*, the cost of hydrogen from the water gas plant is taken as 10s. per 1,000 cubic feet. He refers, of course, to remarkable gas as on p. 129, it is described as "practically odourless and, though not itself inflammable, it combines readily with oxygen." His helium is also remarkable. "It can only be manufactured from uranite (pitchblende) or other rare earths and minerals."

He estimates the performance and describes the characteristics of several ships of various sizes, from the 4,000,000 cubic feet ship to the small non-rigid for private pleasure. His 60-ton ship with a speed of 85 miles per hour, passenger

accommodation for 100 passengers and in addition a disposable lift of 24 tons, seems at present far off; as is also his 11-ton non-rigid with a disposable lift of five tons.

A great feature is the passenger accommodation on the top of the large ship, including promenade deck saloons, etc., etc. What proportion of the 55 tons allowed for all fixed weights of this ship would be represented by the weight of decking 250ft. long by 22ft. wide? An open promenade deck, even at the cruising speed of 60 miles per hour, might involve eddies very disturbing to some passengers at any rate. He expects (p. 94) a group of three airships to make 104 trips per year of 3,500 miles, *i.e.*, 2,200 actual flying hours per year *per ship*, and to go on doing it for four years.

The object of the book is presumably to demonstrate the soundness of commercial airship transport. Several points which he raises scarcely appear sound policy. In discussing the merits of the airship by comparison with the aeroplane, he does his best with the estimate of speed, but omits his two best shots—(1) that an aeroplane flying only by day at least halves its effective speed on a long passage, and (2) that being limited to comparatively short trips the aeroplane course cannot be chosen to take full advantage of trade winds and meteorological conditions.

The author points out that the aerodrome required for an airship may be smaller and of less firm and even surface than that required for aeroplanes. Is it not intended that airship freight should be distributed by aeroplanes, and changing aerodromes by motor lorry is unthinkable.

On p. 169 he affirms that "things are usually arranged so that the tanks or bags themselves can be dropped overboard in the event of water being frozen." This scarcely helps to convert the timid to a desire to have a commercial airship line running over their bedrooms.

Some of the explanations are wrong technically.

Page 120.—The airship "will continue to ascend until . . . the dynamic lift just balances the reduction of gas lift due to gain of altitude. . . . On the other hand she can be driven downwards until the thrust is equal to the gain of lift when it becomes necessary to valve gas." This is obviously very loosely worded, but it certainly seems that the author really does think that the lift increases with decrease of height.

Page 168.—"An airship is in a state of ascensional stability when the lifting power of the ship and the weight of her are exactly equal and the smallest excess of lift is sufficient to cause a descent." We should like to observe this "state."

On *pages* 123, 124 he tells of directional wireless that at ranges of 2,000 miles with an accuracy of a quarter of a degree "allows great circle lines to be drawn on the chart, etc." (Drawing the great circles is hard enough for those who have tried it.) Also of the Bellini Tozi system in which one "sends out signals in various directions to be caught by land stations and the compass bearings noted."

The purpose of the following is difficult to appreciate, *page* 37.—"If a great storm is encountered with such a head wind that the ship cannot reach its destination, the ship should turn and run with the wind." Unless it be to show what a really vast reserve of petrol an airship can carry.

On *page* 157 he explains that the velocity of gas leaving the exhaust valve is about 2,500ft. per second. The noise of the open exhaust is due to the issue of gases at a velocity higher than that of sound and the main disturbances are suppressed as soon as the velocity is brought below 1,140ft. per second, the velocity of sound in air.

It is most disappointing that a book, which by its title and author promises to be of such great value, should for the reasons indicated above fail to fill the very great need which still exists for a sound book on technical airship matters.

OBITUARY.

THE LATE MAJOR LINTON HOPE, M.I.N.A.

" '*Would'st thou,' so the helmsman answered, 'know the secret of the seas?'* "

Major Linton Hope sailed before the mast, and worked as a carpenter and boat builder, on which solid foundation he based his study of Naval Architecture, specialising in light resilient construction. His many published writings and books form an unequalled body of authoritative information on the subject.

As a member of the Institute of Naval Architects, as Consulting Naval Architect to the King of the Belgians, and as a prominent member of the Yacht Racing Association, he exercised a sound influence on the technical side of his profession, while as a clever helmsman and a keen sportsman, he carried many flags at the end of a season's racing.

Useful inventions marked his mechanical aptness. All classes of yachts, sailing dinghies, skimming dishes and motor boats showed the soundness of his principles and the versatility of his applications by their variety and success.

The cruising schooner " Molihawk III." (90-tonner), the Hope-Thorneycroft Hydroplane, and the 1-rater " Sorceress " may serve as examples. The combination of strength and lightness, for which his hulls were distinguished, marked him as the very man to bring into consultation on the design of hulls for sea-aeroplanes. His first design, the A.D. boat, was a revelation to hull designers, and his P.5 hull set a standard which will remain for many years. He professed having little knowledge of formal mathematics, yet he was deeply imbued with the true spirit of the *geomètre*.

Probably he never, in his life, wrote down the second differential coefficient of the simplest function, yet his eye detected at a glance the slightest discontinuity in the second differential coefficient of a boat line.

The calculus of variations was less known to him than Greek, yet his variation of hull lines to yield the " best " compromise was a masterly application of its principles.

His modesty of manner concealed from superficial acquaintance his great talent, amounting to genius in his own line of work. There was nothing patchy about his hull designs; they were finished with high craftsmanship to the last detail.

His personal friends will long cherish remembrance of the charm of his companionship.

THE

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(FOUNDED 1897 in succession to the ANNUAL REPORTS).

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Edited for the Council by J. LAURENCE PRITCHARD, Associate Fellow.

All communications should be addressed to the Editor.

No. 122. FEBRUARY, 1921. VOL. XXV.

Notices of the Royal Aëronautical Society.

Election of Members.

The following members were elected in the various grades as shown at a Council meeting held on January 25th, 1921:—

Associate Fellows.—Captain E. E. Aldrin, U.S. Air Service, Wing-Commander E. F. Briggs, D.S.O., O.B.E., Flight-Lieutenant F. L. C. Butcher, S. Payne, Esq., M.I.N.A., Hon. R.C.N.C., W. P. Rogers, Esq., A. J. Spencer, Esq., A.M.I.Mech.E., E. P. Warner, Esq., R. P. Wilson, Esq., C.B.E., M.Inst.C.E., M.I.E.E.

Students.—Captain W. C. Cooper, H. A. Dalton, Esq., J. G. Edenborough, Esq., F. A. Kerry, Esq., G. E. Page, Esq., A. P. Rowe, Esq., Flying Officer A. V. Shewell.

Members.—H. A. Crook, Esq., J. J. Holt, Esq., H.H. the Maharaj Rana of Jhalawar, Squadron Leader H. R. Nicholl, O.B.E.

Associate Members.—L. K. Forbes, Flying Officer F. L. Hopps, A.F.C.

Foreign Members.—J. McAllister Allan, Esq., Lieut. R. Arisaka, I.J.N., L. Mapelli de Pietro, Esq., Lieut.-Eng. H. N. Pantolini, Arg. Navy, Lt. Commander Louis Sablé, French Air Attaché.

Lectures.

Members are reminded that invitation cards for lectures which are held at the Royal Society of Arts, John Street, Adelphi, are no longer circulated to members; the only notification of lectures or special arrangements being, save in exceptional cases, contained in the Weekly Notices in the Press and notices in the Journal.

The lecture arrangements for the remainder of the present Session are as follows:—

Feb. 3rd, 5.30 p.m.—Major G. Dobson, "The Use of Meteorology to Aviation and Vice-Versa."

Wing Commander H. W. S. Outram, Assoc. Fellow, "Ground Engineering."

Chairman: G. C. Simpson, Esq., C.B.E., D.Sc., F.R.S., Director of the Meteorological Office.

Feb. 17th, 5.30 p.m.—F. Handley Page, Fellow, "The Handley Page Wing."

March 3rd, 5.0 p.m.—J. W. W. Dyer, "Airship Fabrics."

Major T. Orde-Lees, A.F.C., "Parachutes."

Chairman: Air Commodore E. M. Maitland, C.M.G., D.S.O., A.F.C.

March 17th, 5.30 p.m.—Capt. D. Nicholson, Associate Fellow, "Flying Boat Construction."

Scottish Branch.

It is regretted that the title of the newly-formed discussion society in connection with the Scottish Branch was incorrectly given in the last issue. The title should read, "The ex-Airmen's and Students' Section of the Royal Aëronautical Society (Scottish Branch)." The Honorary Secretary is Mr. C. R. Catesby, "Highfield," Croxley Green, Herts.

Committees.

For the information of members it may be stated that the Council, Candidates' Qualifications Committee, and Lectures and Publications Committee meet monthly at the Society's Offices in the afternoon of the third Tuesday in each month. Other committees meet as and when required.

Technical Terms Committee.

It has been arranged with the British Engineering Standards Association that the revision of the "Glossary of Aeronautical Terms," published by the Society in 1919, shall be continued under the auspices of the Association. The Technical Terms Committee of the Society, which also acted as Aircraft Sub-Committee No. 1 (Nomenclature) of the B.E.S.A., has been placed at the disposal of the Association for this purpose.

Revision of Rules.

The consideration of the Secretary's draft amendments to the rules was considered at the January Council meeting and will be completed at the next meeting, on February 15th. They will then be brought before the Annual General Meeting for confirmation.

Membership Card.

The design of a card of membership for issue to each member was approved by the Council at their January meeting, and this will shortly be issued.

Library.

The following books have been received during the month and placed in the library:—"The Theory of Direct Current Dynamos and Motors," by John Case, M.A., A.F.R.Aë.S.; Meteorological Pamphlets presented by the Smithsonian Institution; Official Year Book of Scientific and Learned Societies, 1920; "Rendiconti Dell'Istituto Sperimentale Aeronautico di Roma," September, 1920; "Clouds," by George A. Clarke, F.R.P.S., F.R.Met.Soc.

Arrangements for the Month.

Feb. 3rd,	5.30 p.m.	*Lectures.*—"The Uses of Meteorology to Aviation and Vice-Versa," by Major G. Dobson. "Ground Engineering," by Wing Comdr. H. W. S. Outram. *Chairman*: G. C. Simpson, Esq., C.B.E., D.Sc., F.R.S.
Feb. 15th,	4.0 p.m.	Lectures and Publications Committee.
	4.30 p.m.	Candidates' Qualifications Committee.
	5.0 p.m.	Council.
Feb. 17th,	5.30 p.m.	*Lecture.*—"The Handley Page Wing," by Mr. F. Handley Page.

Lord Invernairn of Strathnairn.

Members will no doubt wish to join in congratulating Sir William Beardmore, Chairman of the Scottish Branch of the Society, on his elevation to the peerage. It is understood that he has chosen as his title "Lord Invernairn of Strathnairn."

W. LOCKWOOD MARSH, *Secretary.*

Synopsis for Paper on Parachutes to be read before the

ROYAL AERONAUTICAL SOCIETY,

BY

MAJOR T. ORDE LEES, A.F.C., O.B.E.,

3rd March, 1921.

Title—

REDUCING LOSS OF LIFE IN AIR-WRECKS.

Observation that parachutes have only recently received scientific consideration

Pros and Cons of Parachutes.

Statistics of lives saved by parachutes.
The controversy as to their practicability on aeroplanes.
The British view.
The German data.
Objections to parachutes on aeroplanes.
Statistics of effect on performance of aeroplane.
Estimate of men who jumped from burning machines.
Authentic cases where parachutes could have saved life.
Parachutes useless in the majority of accidents.
Estimate of percentage who could be saved from aeroplanes.
The official adoption of parachutes on aeroplanes by the R.A.F.

Parachutes and Civil Aviation.

Civil aviation must follow suit sooner or later.
Objections to fitting parachutes to civil aircraft.
Parachutes and the pressure of public opinion.
Recent crashes in which parachutes might have saved lives.

The Big Machine Problem.

The baffling problem of the multi-passenger machine.
Existing solutions.

Some Inventions.

Useless parachute inventions.
Common parachute fallacies.
American parachute patents.
Inadequate parachutes.
Parachute-flying-machine ideas.

History.

The investigations of Leonardo da Vinci and Montgolfier.
Early parachutists. (Very lightly touched on.)
Cocking's experiment. (Ditto ditto.)
The parachuting of bursting balloons.

Various Types of Parachutes.

The parachute machines of De Groof and Le Tour.
Why aeroplanes cannot act as parachutes. An exception.
Falling speeds.
Minimum parachute dimensions.
A parachute overcoat which killed its inventor.

Various Types of Parachutes.

The various existing systems of parachutes. Pros and cons.
Extraction parachutes.
Pégouds wonderful experiment.
The first man to jump from an aeroplane.

Action of Parachutes.

The action of a parachute launched from an aeroplane.
The effect of forward momentum.
Terminal velocity.
Variable speed parachutes and the reason for them.
Dirigibility.
Positive extension.
Positive opening; its vital necessity.
Tangle-proofness.
Either side delivery.
Any position parachutes.
Dragging.
Quick releases.
Demonstration drops.

Can Parachutes Help to Save Civil Aviation?

Inability of air passengers to use parachutes.
The overwhelming incentive of fire.
Statistics of civil aviation fatalities.
Comparison of air fatalities with railway and marine fatalities.
The City man's view towards air transport.
The imperative need of rendering air-travel safer.
The parachute's part in the future of aviation.

PROCEEDINGS.

FIFTH MEETING, 56th SESSION.

The Fifth Meeting of the Fifty-Sixth Session was held on Thursday, December 2nd, 1920, in the Hall of the Royal Society of Arts, London, Air Marshal Sir Hugh M. Trenchard presiding.

The CHAIRMAN said it was a great honour to be asked to preside at the reading of these particular papers. He need hardly say how interested he was or that he had been reading every scrap of information he could get both on airship mooring and airship piloting. It was not necessary for him to introduce Major Scott. He was well known as the pilot of the R.34 which flew to America. He would ask him at once to read his paper.

Major G. H. SCOTT, C.B.E., A.F.C., then delivered the following lecture:—

AIRSHIP PILOTING.

I feel it a great honour to have the privilege of addressing the members of the Royal Aeronautical Society on the subject of Airship Piloting, especially in view of the interest you have taken in furthering and generally assisting in the development of all types of aircraft.

Although the airship has hitherto not occupied the thought and brains of Aeronautical Engineers to the same extent as the aeroplane and seaplane, I feel sure the confidence and support of the Society will lead to a more general and scientific interest being taken in lighter-than-air craft, which is bound to result in more rapid progress in the near future.

I hope the discussion to follow will provide the foundation for solving some of the problems that will have to be faced, when piloting the airships over routes to various parts of the world, where totally different atmospheric conditions are likely to be encountered. Once these problems are solved, I feel that the future of the airship as a mode of fast long-distance transport is assured.

In the early days of sea-going ships, the captain of the ship worked the helm, and by his own personal observation and skill at the helm, navigated his ship in unknown seas, but his progress was slow and the distance covered comparatively small.

As the size of the ship increased, the captain handed over the helm to one of his men, and turned his attention to the navigation and the general working of his ship. As the ship grew bigger still, and the speed and range increased, he relegated more duties to his junior officers and turned his attention to the control and co-ordination of the whole.

It is the same with the airship. In the early days when airships were small, the pilot himself worked the controls, but as the size increased he turned his whole attention to the navigation and general piloting of his ship, his crew working the controls. Thus the captain of the large airship of the future, although having an intimate knowledge of the detail working of the airship, will merely control and

direct, and his chief study will be the weather, and the best method of using it, to make a quick, safe passage.

It is this side of piloting that I will chiefly consider in this Paper, and will deal with it under four heads—

(*a*) Aerostatics of Airships.
(*b*) Aerodynamics of Airships.
(*c*) Weather with regard to Airships.
(*d*) Navigation.

AEROSTATICS.

Before discussing the piloting of airships, it is necessary first to appreciate the statical conditions which govern their performance.

(*a*) Lift of Hydrogen.

In modern airships the gas used to give the buoyancy or lift is hydrogen. This gas has a weight of only 1/15 the weight of an equal volume of air at the same temperature and pressure.

That is at normal temperature and normal atmospheric pressure, 1,000 cubic feet of hydrogen weighs approximately 5lbs., whereas 1,000 cubic feet of air weighs 75lbs.

So that under usual conditions pure hydrogen has a buoyancy or lift in air of between 70lbs. and 72lbs. per 1,000 cubic feet.

In practice it is impossible to obtain or maintain pure hydrogen in the airship, it is therefore necessary to know the degree of purity.

This is determined by means of a purity meter, which gives the relative density between the air and the hydrogen under test.

The relation between air and pure hydrogen is known, so that a relation can be calculated between the hydrogen tested and pure hydrogen. For convenience, it is assumed that the impurity is air, and the " purity " is expressed as the percentage by volume of hydrogen in a mixture of hydrogen and air, which would give a similar density to that of the mixture of gases tested. Thus a purity of 90 per cent. means a density corresponding to a mixture of 90 per cent. pure hydrogen and 10 per cent. pure air at the same pressure and temperature.

This figure has to be applied in calculations of the lift of hydrogen, and the true lift is obtained by multiplying the lift of pure hydrogen by its per cent. purity.

(*b*) Effect of Barometer on the Lift of Hydrogen.

As an airship has a fixed maximum volume, it is usual to deal with the lift of hydrogen for a fixed volume, 1,000 cubic feet is usually taken as the unit of volume.

With alterations of barometer, the density of the hydrogen and the density of the air displaced, and therefore the lift of the hydrogen, varies.

For the purposes of calculation, Boyle's Law is sufficiently accurate.

Thus $PV=K$, or the density is proportional to the pressure, that is, the lift of a fixed volume of hydrogen is directly proportional to the pressure of the barometer.

It is assumed that the same pressure exists inside and outside a gas bag. No correction has, therefore, to be made in the case of temperature.

(*c*) The Effect of Temperature on Lift of Hydrogen.

The density of air and hydrogen vary with temperature, and assuming a constant pressure the density varies according to Charles' Law, or the density

varies inversely as the absolute temperature, therefore the lift of hydrogen varies inversely as the absolute temperature.

Taking temperature, purity and barometric pressure, the lift of hydrogen is given by

$$L = \frac{B}{T} \times P \times K.$$

where L = Lift per unit volume of the gas.
B = Barometric pressure.
T = Absolute temperature.
P = Percentage purity of the gas.
K = Constant, depending upon the units used.

Superheating.

In the foregoing consideration of the lift of hydrogen it is assumed that the hydrogen and air are under the same pressure and temperature. In practice this is reasonably correct with regard to pressure, but with regard to temperature very big differences can be experienced.

Thus when an airship is flying through a warm sun, the temperature of the gas is raised above that of the surrounding air. This condition is termed superheating, and in British practice is measured by the number of degrees Fahrenheit between the temperature of the air and the temperature of the gas. Thus a 10° superheat means the gas is heated 10°F. above the surrounding air.

The Effect of Superheating.

If an airship contains a known quantity of hydrogen, that is, a known weight of hydrogen, and the temperature and pressure of the hydrogen are the same as that of the air displaced, then the lift of this fixed weight of hydrogen will remain constant whatever the pressure and temperature.

Thus in a rigid airship where the gas bags are not full, the ship can rise or fall, and as long as no gas is lost and no superheating takes place the lift will remain constant.

In practice a rigid airship is seldom full of hydrogen, and I will deal with the effect of superheating on an airship under this condition.

The volume of the gas in the airship depends upon the barometer and the temperature of the gas, and is given by

$$V = \frac{T_1}{B} \times K$$

where T_1 is the gas temperature.

Now this is the volume of air displaced, so that the lift of this gas is given by

$$L = \frac{B}{T_2} \times K \times V$$

where T_2 = air temperature,

$$\text{or } L = (T_1/T_2)\,K.$$

Thus the lift of the gas is increased on superheating and is calculated by taking the lift without superheating and multiplying by

$$\frac{\text{the absolute temperature of the gas}}{\text{the absolute temperature of the air}}$$

Or the increase in lift due to superheating = lift without superheating multiplied by

$$\frac{\text{the degree of super-heating (\textit{i.e.}, difference between gas and air)}}{\text{absolute air temperature of air.}}$$

This quantity is known as the false lift.

There is an error in the above method owing to the fact that the weight of 1,000 cubic feet of hydrogen varies with the temperature, and it is therefore not correct to assume that the lift is directly proportional to weight of air displaced. In the above the temperature of the gas is only taken into consideration to obtain the new volume of the gas.

This error is, however, comparatively small, and is therefore neglected in practice in order to simplify the calculation.

A condition occasionally arises when the gas temperature is lower than the air temperature; the decrease of lift in this case is known as latent lift.

Aerodynamics.

The study of the aerodynamics of airships is primarily a design problem, but it is so inseparably connected with piloting that I cannot neglect the subject in this Paper, especially in connection with future and larger ships.

Head Resistance.—The head resistance of airships of the same form for the same velocity varies as the (capacity) $^{2/3}$ and the lift varies as the capacity.

The per cent. total weight of the airship required for propelling machinery to give a constant speed, therefore, decreases as the size increases, or, with a constant per cent. of machinery weight, the speed of an airship increases as the (capacity) $^{1/9}$ or as the $\sqrt[3]{\ }$ length.

At this increased speed the range for the same per cent. weight of petrol carried is also increased, so that for ships of the same form of the same per cent. weight of machinery and the same per cent. weight of petrol carried the speed and range each vary as the (capacity) $^{1/9}$.

Dynamic Lift.—The dynamic lift of an airship may be defined as the component at right angles to the flight path of the resistance of a ship moving through the air with its centre line inclined to the path of flight.

It is the vertical component of this dynamic lift that is employed to maintain an airship at constant altitude, or to drive her up or down, when the ship is not in static equilibrium, that is, when the lift of the gas is greater or less than the weight of the ship and her cargo.

With ships of similar form this dynamic lift may be taken as proportional to the resistance for the same angle of flight, or to borrow a term from H/A, the same "attitude" of flight.

Thus if the same per cent. weight of machinery is employed the maximum dynamic lift (expressed as a percentage of the displacement) varies as (capacity) $^{8/9}$ so that practically the same degree of superheating can be dealt with.

But if a constant speed were maintained and the capacity increased, the per cent. weight of machinery would be decreased, and therefore the degree of superheating that could be dealt with without loss of gas would decrease.

In the design of large ships this fact must not be overlooked, or for large ships with a long range it may be necessary to carry so much water ballast that the advantage gained by increase in size may be nullified.

Controllability.

As there are so many factors that affect the controllability of an airship, I fear I cannot deal summarily with the subject.

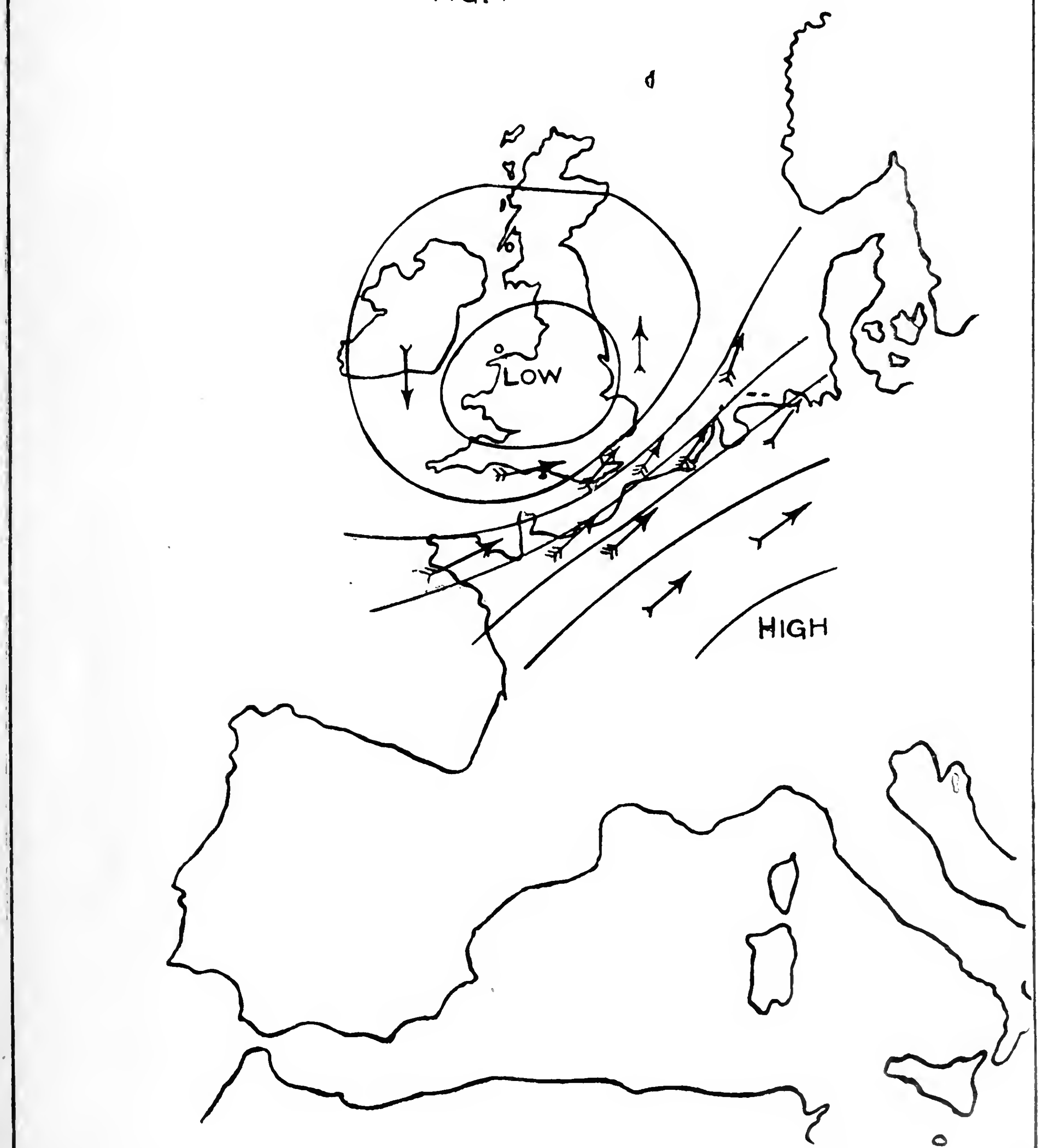
A stream-lined airship if travelling through the air at a small angle to the axis of the ship, instead of tending to return to the direction with its centre line parallel to line of motion tends to increase this angle.

This has a marked effect on the controllability when a ship is flown " light " or " heavy."

Thus when a ship becomes light she appears to be nose heavy, and conversely when she becomes heavy she appears to be nose light.

This effect acts in favour of the pilot at certain speeds, but at high speeds, when a ship is more than a certain per cent. light or heavy, the effect becomes so

FIG. 1



great that the elevators cannot cope with it, and the ship, if heavy, will continue to climb, or if light continue to dive.

The correction if such a case should occur is to slow down the engines.

In the event of the elevators jamming, this unstable property of a stream-lined ship can be employed to pilot a ship back to her base.

The German airship pilots have experienced this effect, and in L67 the horizontal fins are placed on the hull at a permanent angle down by the tail. This allows the ship to fly very heavy, thus permitting the pilot to take his ship to a great height when raiding, allowing for the release of weight in bombs and petrol used to bring his ship to equilibrium before landing.

FIG. 2

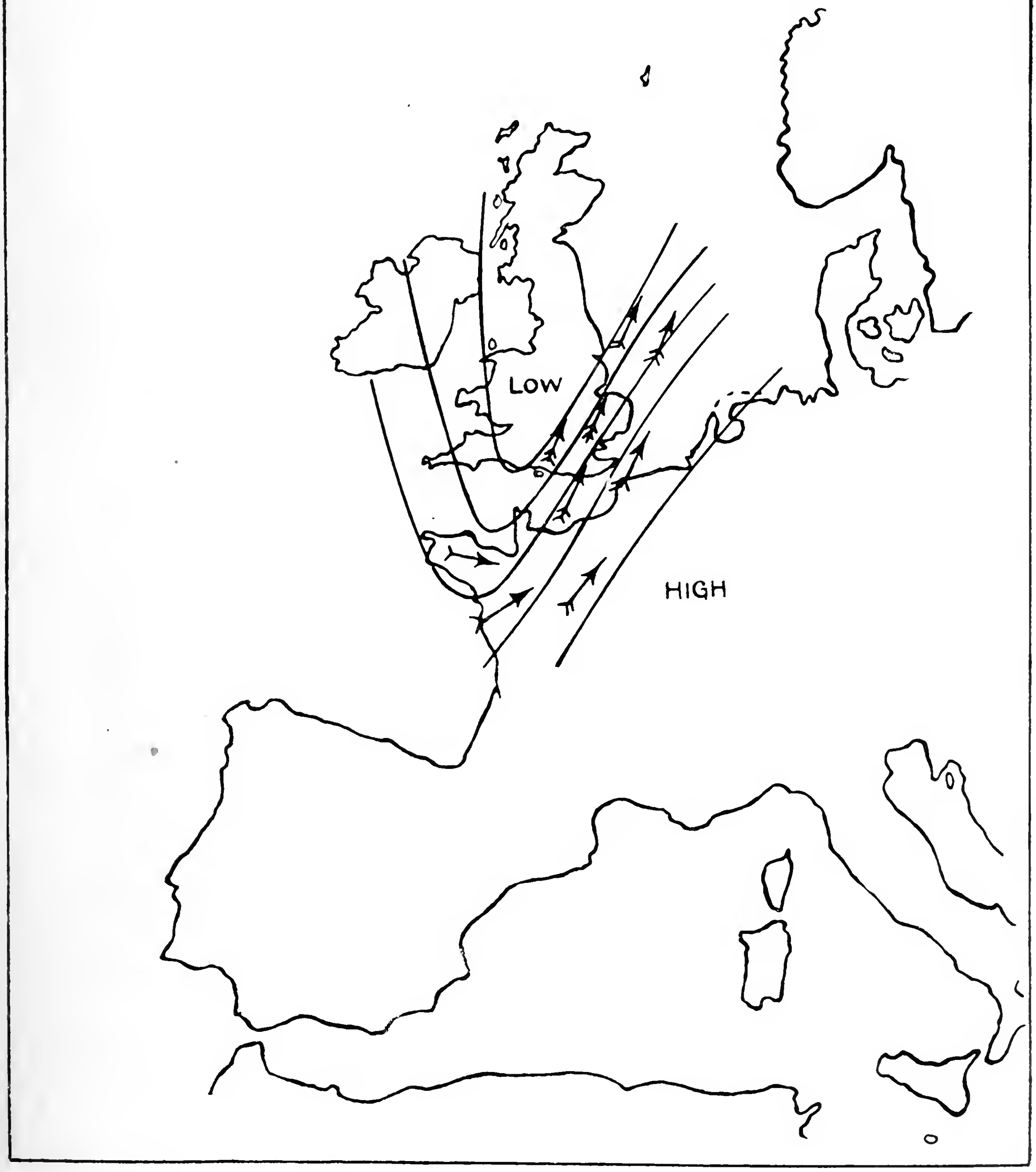
A more detailed consideration of the forces acting on a ship under this condition is given in Appendix A.

Weather.

There is a general idea that an airship is a fine weather craft. This is only partially correct.

An airship up to the present time has been under the disadvantage of having to leave and enter its shed at the beginning and end of each flight, and as there

FIG. 3



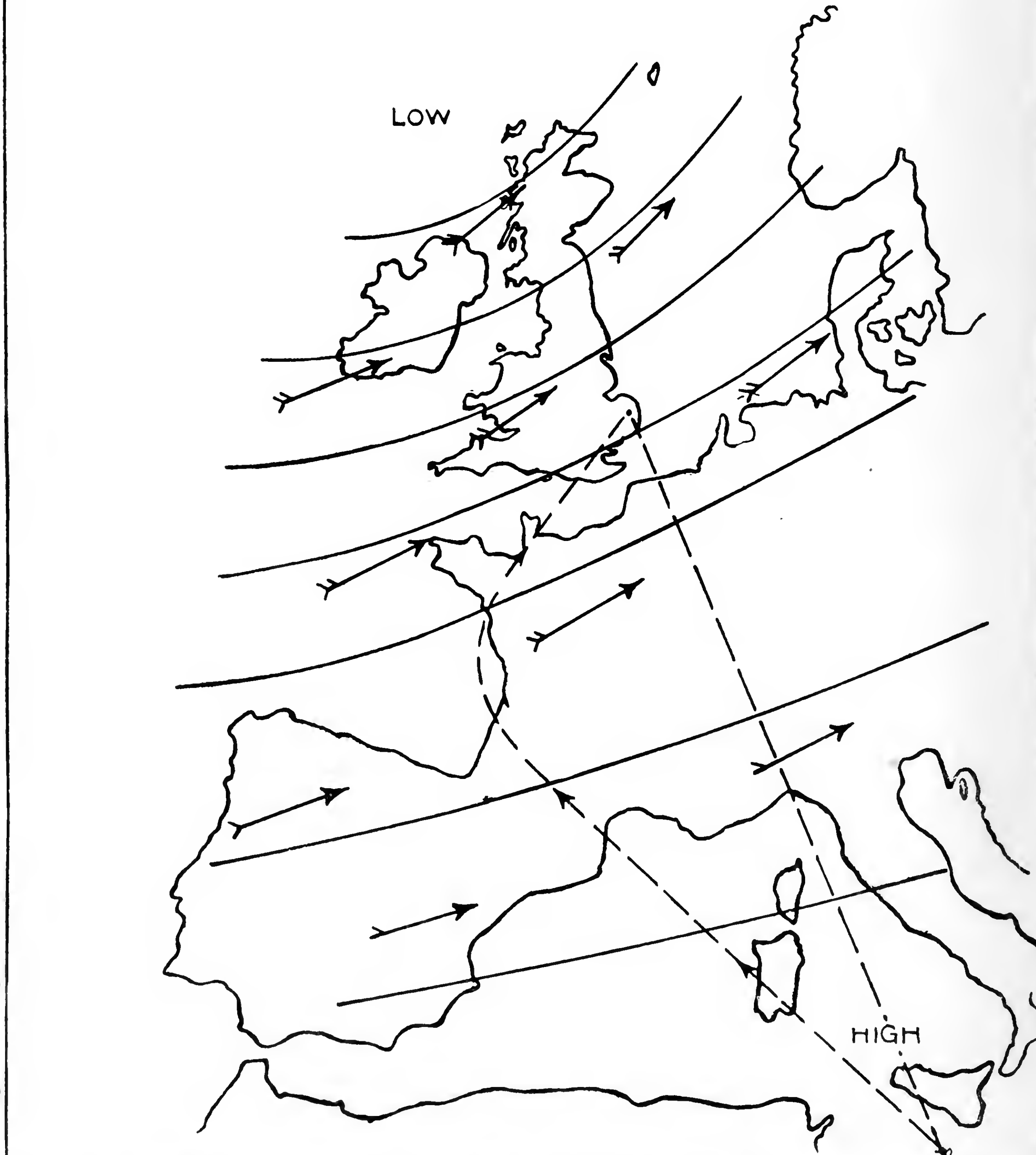
is difficulty in handling a ship in and out of her shed in strong winds, this has limited the application of the airship in the past to fine or moderate weather.

An airship once in the air is not a fine weather craft, and a large ship with a good range and speed need not fear any type of weather.

Experiments are at present in hand which will allow of an airship landing or leaving a mooring mast or tower in strong winds, and when these experiments are completed there is little doubt that an airship will be almost as independent of the weather as sea-going passenger liners.

I will divide up weather into groups and discuss each separately.

FIG. 4.



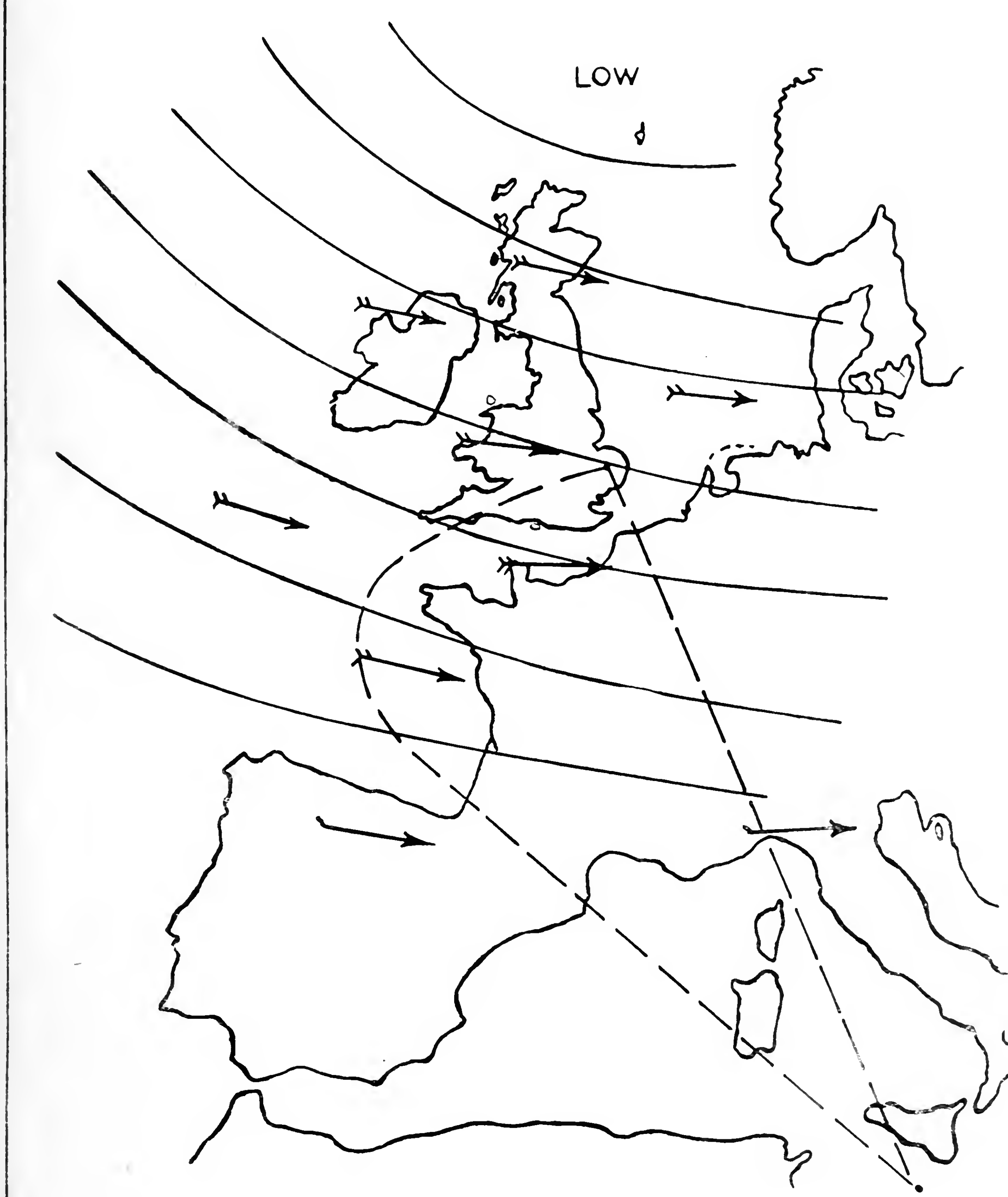
(*a*) **Wind.**

Strong winds in this country and in the Atlantic are caused by depressions or cyclones. These cyclones are approximately circular in form with the wind blowing round them in a counter clockwise direction with a slight bearing towards the centre or low pressure zone.

They vary very considerably in size, and may cover half the Atlantic or be only 200 miles in diameter. The larger the depression the longer warning we have of its approach, and therefore the easier it is to avoid or utilise.

Also, except in rare cases, a very large depression is only associated with very high winds, over a comparatively small area.

FIG. 5



The strength of the wind is largely dependent upon the distance apart of the isobars. The shorter this distance the stronger the wind. It is obvious, therefore, that where the winds are strong and the isobars close together the area covered must be small.

Thus a pilot, on meeting a strong wind, turns broadside on to the wind, and in a very short time he will be through the bad zone and in a light or favourable wind. It will be seen that the time taken for the ship to cross the bad weather zone does not depend upon the strength of the wind but upon the speed of the ship, also that the amount the ship drifts out of its course depends, on the other hand, on the time taken and the speed of the wind. It is therefore necessary that the ship should have a good turn of speed, so as not to be driven too far out of her course.

Except in very rare circumstances, such as when the base at which the pilot wishes to land is in the bad weather zone, a pilot should never beat directly into a strong wind, and even in the above case it often pays to lie off for a few hours, as the movement of the centre of the depression will move the area of strong wind away from the base.

It is owing to this movement of the centre of a depression that, except in exceptional circumstances, a very strong wind does not blow for very long in one place. I have pointed out above the general method of dealing with strong winds, and endeavoured to explain that they are not a serious obstacle to the airship and should not interfere much with schedule flights.

A much more difficult wind for the airship pilot to deal with is a head or beam wind of from 20 to 30 miles per hour, as this may blow over a comparatively large area and for long periods.

In order to deal with this wind, good meteorological reports must be at the pilot's disposal, and he must vary his course sometimes 12 to 24 hours ahead in order to circumvent such a wind. As an example, the pilot is flying from Malta to Norfolk, there is a large depression centred N.W. of Scotland, giving a westerly and south-westerly wind over the South of England and North of France. If the pilot endeavoured to make good a direct course from Malta to England he would be obliged to edge up into a 30-mile broadside wind over several hundred miles, and the time taken for the journey would be greatly increased.

If, however, the pilot was supplied with good meteorological information he would set his course so as to pass out into the Bay of Biscay, just north of the Pyrenees, and when he encountered westerly winds of increasing force he would turn north at right angles to the wind and use the drift to make his base. Thus during no part of his journey would he be heading into a wind, and although the course taken is somewhat longer than the direct route, the time taken will be very little in excess of the still air time, and with a reasonable amount of spare engine power the airship could still make its scheduled time on the journey.

Necessity of knowing true height above surface.—In order to use the meteorological information to the best advantage, the pilot should be in a position to read the ground barometric pressure at any moment, so as to know whether he is approaching the high pressure or low pressure zones, or flying parallel to the isobars, and thus estimate the rate of movement of the depression.

This is impossible at present, as there is no known method by which a pilot can measure with accuracy or regularity his true height above the surface. Thus the barometric pressure measured in the ship gives no accurate measurement of the surface barometer.

Some instrument or method of overcoming this difficulty is most urgently needed.

Effect of height on wind velocities.—At the present time there is not a great deal of data regarding the variation of wind velocities and direction with height. Such data as is available chiefly deals with anti-cyclonic conditions when the air

is clear and a pilot balloon can be sent to a great height. This is the fine weather condition, when the need for alteration of altitude to avoid bad winds is rarely necessary.

The cyclonic conditions over the British Isles are nearly always associated with comparatively low heavy clouds, when it is impossible to follow a pilot balloon to any height, and it is under these conditions that further data is required.

My general experience has been that westerly winds increase with height, whereas easterly winds tend to decrease, both tending to turn anti-clockwise.

We, however, had an interesting experience on R34 on the trans-Atlantic flight which would tend to qualify the above statement.

When within 800 miles of Newfoundland, R34 encountered a shallow depression of about 600 miles diameter and giving a ground wind of about 45 to 50 miles per hour, with low clouds and driving rain. After several hours, during which time we were being driven north, it was decided to climb through the clouds and try to check our position by a sun sight with a cloud horizon. At 5,000 feet we passed clean out of the top of the depression, and into a light westerly wind. This was calculated by cloud drift, and later checked by the time and position we passed over the Newfoundland coast. Thus in this case, by rising a few thousand feet, we avoided the strong southerly wind which was blowing at the surface.

I very much doubt if in the ordinary case over land the comparatively low height to which R34 ascended would have helped us very much, but it rather pointed to the fact that over a large expanse of water like the Atlantic many depressions do not rise to the high altitudes generally supposed.

In this case, as in many other cases, the heaviest clouds were situated where the wind change took place.

Permanent Winds.—The advent of the steam ships has to a large extent reduced the value of the permanent winds of the world, but these winds played a great part in the early development of the Mercantile Marine, and are destined to play a great part in the development of aerial commerce.

It was due to the position of Spain, situated almost in the trade winds, that gave her such an advantage in the development of Central and South America, and it is interesting to note that all the Spanish possessions in America were situated so as to use the trade winds.

The permanent winds of the world may be divided into two classes: (1) The easterly or trade wind, which blows north and south of the equator in easterly direction and towards the equator; (2) The westerly drifts, which are found in the Arctic and temperate zones.

The principal westerly drifts are in the North Atlantic, where they are modified and interrupted by the cyclones which pass over this region, and the great westerly drift round the Antarctic Continent which affects the southern part of the South Atlantic, the Indian Ocean and the South Pacific Ocean.

There are also many smaller permanent winds and also seasonal winds, such as the Monsoons.

In considering the future airship routes of the world, these winds must be taken into account.

Examining the probable routes to Australia and South America, it will be seen that the tendency is for the westerly journey to be made near the equator, using the trade winds, whereas the easterly journeys are always farther from the equator so as to use the westerly drifts. The gain in speed and regularity is so great that even with greatly increased speed it is still advisable, where economic conditions allow, to choose a route that will employ these winds.

Height of Trade Winds.—Although the area of the trade winds is well-known and well-defined, very little is known except of the surface winds, and it is very important that further investigations should be carried out to find to what height these winds extend and if there is a return westerly wind at any reasonable height.

Over the West Indies the greatest force is found at between 2,000 and 3,000 feet, and a falling off in wind velocity occurs above this. It is probable that well clear of land the greatest velocity is even lower, and comparative calm or a return or trade reversal wind will be encountered at no great height. If this is found to be the case the commercial value of these trade winds will be enormously increased.

Convectional Winds.—These winds, compared with the permanent winds, are very local; they are met with all over the world, and are due to the uneven heating of the earth's surface. Land and sea breezes are of this class, also the permanent northerly wind over Egypt. Convectional winds are met with in the Atlantic where the gulf stream and Labrador currents travel parallel to each other. They are of distinct use to the pilot who understands them and knows how to make use of them, but owing to their small area they are, of course, of small importance compared to the permanent winds.

(*b*) Temperature.

I have already described superheating under aerostatics and aerodynamics, but have given no indication as to the degree that may be expected or best method of reducing this effect.

In most cases superheating is due to direct heat from the sun, and is therefore likely to be much more serious near the equator, but until flights are carried out in tropical or semi-tropical climates it is difficult to estimate the degree that we may expect.

The effect of the sun is to raise the temperature of the gas, and the maximum temperature obtained in still air depends upon the sun's intensity, without respect to the surrounding air. The degree of superheating, however, is the difference between this temperature and the temperature of the surrounding air, so that the higher the temperature of the surrounding air the lower the degree of superheating for any known sun's intensity.

The sun's intensity tends to increase with height whereas the air temperature generally decreases, so that the best method of reducing superheating is to fly low.

The greater the degree of superheating or difference of temperature between the gas and the air, the more efficient the cooling due to the ship's motion through the air, but the result will still be a greater degree of superheating with height.

The type of outer cover is also a big factor in superheating; the better the outer cover the greater the amount of sun's rays reflected, and therefore the less heat absorbed which has to be dissipated to the air by the motion of the ship, and therefore the lower the temperature of the gas.

Speed also plays a part, as the higher the speed the more easily is heat carried away by the air; so that the best method under most conditions to reduce excessive superheating is to go fast and fly low.

Inversion of Temperature.

There are certain conditions when the temperature of the air on the ground is lower than the temperature at a height. This occurs at certain times of the day in many parts of the world, and when such a condition is encountered the pilot will only increase his superheating by flying low.

R.34 encountered a very marked example of this over the ice fields off Newfoundland. The lower air was cooled to below freezing by the ice and the sun was very powerful owing to the clearness of the air above.

The maximum superheating on this occasion was as much as 40deg.F. at 4,000 feet, which is the greatest I have yet encountered.

An inversion of temperature may cause trouble when leaving the ground if unexpected, as if a pilot ballasts up his ship just slightly light on the ground he will find it practically impossible to force his way up into the hot air above, and as this inversion is often found at only 200 to 300 feet, there is a serious danger of hitting some obstacle.

This condition is more generally encountered in the tropics.

Method of Superheating to Reduce Gas Consumption.

Superheating is not always a drawback, as if a ship leaves the ground during the heat of the day when highly superheated, and lands again at night with no superheating, the loss of lift due to the false lift which disappears after sunset will partially or wholly counterbalance the weight of petrol consumed, so that little or no gas need be expended.

Electric Storms.

Electric storms are the airship's greatest danger. There is not a very serious danger from lightning, as on at least two occasions German airships have been struck without causing serious damage.

The chief dangers from electric storms lie in the very serious bumps and eddies that accompany them; these can be extremely violent and very seriously stress the structure of the airship.

The electric storms are generally confined to certain areas and certain periods of the year; also it has been my experience that an electric or thunderstorm follows a very definite track, and there are many places both in England and abroad where a thunderstorm is unknown; it may pass within a few miles but never over that particular spot.

It should therefore be possible to chart the disturbed areas and tracks of storms, showing the areas immune from storms. If such a chart was available, and reasonable warnings are given, it would be extremely bad pilotage for a captain of an airship to allow his ship to be overtaken by a thunderstorm.

My experience has also been that thunderstorms do not travel out to sea; they may follow a line of islands, or cross from one mass of land to another, but they always tend to hug the coast; I have also never met a thunderstorm at sea. I am, of course, speaking entirely of the temperate zone as I have no experience of the tropical thunderstorm.

It is of particular importance that data on this subject should be collected.

Instrument for detecting direction of a thunderstorm.—This instrument would be of very great value to an airship pilot, as for many years to come he will of necessity be flying over regions only partially charted, and the fact of knowing from which direction the atmospherics are coming will enable him to avoid disturbances.

Electric Disturbances at Great Height.

There is very little doubt that very violent thunder or electric storms take place at high altitudes, of which there is no indication on the ground.

R.33 recently encountered such a storm, and neither the wireless nor meteorological instruments at Howden gave any indication of the disturbance; reduction in height would be a method of avoiding such a disturbance.

In the same way under certain conditions when violent atmospherics are encountered at low altitudes, higher altitudes may be free from disturbance.

Clouds and Fog.

Neither clouds nor fog seriously inconvenience an airship. With present navigational facilities a good course can be maintained without seeing the ground, and the stability of the airship prevents any inconvenience in flying.

The effect of heavy rain is to make an airship become heavy, but this can generally be avoided by alteration of height.

In a cloud that does not reach to the surface of the earth the dryest part is the bottom, so that if a ship is becoming heavy flying through clouds, the correct method is to reduce height, provided it is inconvenient to fly above them.

When flying over clouds it will generally be found that on the uneven surface the highest points have a tendency to lean over in one direction.

This gives an indication of the relative velocity and direction of the wind above and below the cloud bank. If the top surface is smooth and flat very little difference in wind need be expected.

The use of clouds for weather forecasting is a very big subject, and outside the subject dealt with in this Paper. It is, however, a most important study for the airship pilot, and should be given a more important position than it holds at present.

The observer on the ground is often handicapped by the presence of low clouds which have slight significance for weather forecasting, and is unable to get a good view of the higher and important cloud formation. The observer in the air has not this handicap as he can fly above the low clouds and get an uninterrupted view.

Snow.

The chief danger from snow is that it may, under certain conditions, cake on the bow of the ship and drive it down owing to its weight.

It is, however, only the soft wet snow that tends to cake, and by rising 1,000 feet or more dry snow will be encountered which will not tend to collect on the ship. There is an electric effect felt from flying through dry snow, and the ship is apt to become highly charged, so that it is always advisable to pull up the aerial under these conditions.

NAVIGATION.

(*a*) Dead Reckoning.

This method can only be used when the surface of the earth is in sight, and although in many parts of the world this may be a common condition, over the North Atlantic and the British Isles it is the exception and other methods must be employed.

Over land.—When flying over a well-surveyed civilised country it is merely a question of map reading. If, however, the country is only partially surveyed, the same methods will have to be employed as when flying over the sea.

Over the sea.—The chief instrument used is the Drift Indicator. In this instrument hair lines on glass or thin wires are arranged in a horizontal plane parallel to the earth's surface, and while observing through an eyepiece, it is possible for the pilot to move the glass or wire round until the objects on the earth's surface appear to travel along the lines in the instrument; the angle is then read off between the line of flight of the ship and the line made by the wires. This angle is known as the drift angle, and is given in degrees port or starboard. The direction of flight of the ship is known so that the direction the ship is making good over the ground can be calculated.

On some of these instruments it is possible to measure the speed made good over the ground by timing the passage of an object between horizontal lines at right angles to the drift lines, but in order to obtain a correct estimate of ground

speed it is necessary to know the true height above the ground. The barometer in the ship does not necessarily give this owing to a possible alteration of barometric pressure at sea level or variation in height of land that the ship is flying over, so that this is an additional reason for the design of some instrument to give this true height of the ship above the earth's surface.

In the case where the sun is nearly overhead and the angle of drift is small, another method of obtaining ground speed is to time the shadow past any fixed object.

A true height above sea level can also be obtained by measuring the angle subtended by the length of the shadow with a sextant, the length of the shadow being known.

There is another method that can be employed where the height of the ship above the ground is not a factor.

A drift angle is taken, first with the ship flying on her true course and then with her flying at approximately 45 degrees either side of this course.

With the construction shown the true wind direction and strength is found and the speed made good over the ground can be calculated.

This method necessitates taking the ship off her course, but if she is flown about the same time on both legs of the triangle little time is wasted, and any error in the ship's position can be calculated and allowed for after the wind direction and strength has been determined.

(*b*) Sun and Star Sights.

The only difference between using this method on surface craft and airships is the very large difference in the height of eye, and therefore distance of the horizon; this often makes it difficult to obtain a good sea horizon, so that a cloud horizon or mist horizon has often to be used. These horizons are on the whole satisfactory, but owing to the irregularity of the cloud formation great accuracy cannot be expected, but an average degree of accuracy of about 10 to 15 miles can be obtained, which for most cases is sufficient.

The height of eye above the cloud or mist is obtained by descending to the top of the mist or cloud surface and then rising a definite distance above it. It is advisable to rise a considerable distance above the cloud or mist surface as this reduces the error due to irregularities.

The types of instrument employed are :—

1. Naval Pattern 7in. Sextant.

This type of sextant is most suitable for taking observations to a natural or cloud horizon. It is necessary, however, that the mean of several sights should be obtained, having rejected those which are obviously in error. The disadvantage of this type of sextant, however, is its weight and head resistance owing to its size. For this reason a naval pattern 4in. sextant has considerable advantages for similar observations.

Observations to sea horizon with either of these sextants give fairly good results, but are entirely dependent upon the clearness of the sea horizon and a correct estimation of height for dip allowance. Double altitude observations of the reflection of the object on still water have given very good results, but it is obvious that instances of this kind are not common and that observations to reflection on the surface of the sea, even under best conditions, would not be reliable.

During a 1,100-mile flight round England carried out recently, the performance of various navigation instruments was investigated. The errors in position lines obtained from observations with the 4in. N.P. sextant by observing the reflected

image in a pool was 5 miles and $6\frac{1}{2}$ miles, the result being worked on a single observation in each case.

On other occasions, however, when there was less time to make the observation owing to the smallness of the pool, the errors were considerably greater. It is clear, therefore, that this is not a method which can be of general use.

2. The R.A.E. Bubble Sextant.

This type of instrument is a complete departure from the pattern of the Naval Sextant, and is especially adapted for use in the air. Its main features are a bubble horizon with a combined index and object glass, which is set at different angles by the revolution of a spiral cam, to which is attached a scale graduated in degrees.

The bubble chamber contains alcohol and has a flexible wall which may be extended or compressed by means of a screw, so enlarging or diminishing the alcohol vapour bubble. The bubble itself is formed under a concaved glass roof which may be illuminated at night by a lamp of variable luminosity. The image of the bubble is reflected by means of a prism on to the object glass, which simply consists of a plain sheet of glass which acts as a semi-reflector. The image of the celestial object is seen reflected on this same glass surface, and is brought into coincidence with the bubble by revolving the spiral cam, the angle of inclination of the glass being registered on the scale.

This type of sextant obviously does away with the necessity of a natural horizon, whether land, sea or cloud. In common with all artificial horizons when used in aircraft, however, the level is subject to error due to the acceleration of the machine acting on the bubble.

Semi-diameter calculations are also eliminated by the use of this sextant.

One difficulty with this instrument is to obtain an index error. This, however, can be obtained by suspending a mirror vertically and taking the reading of the image of the observer's eye in the mirror.

On the Cairo to Cape flight the errors in the position lines, from observations with this type of sextant, were from 4 to 12 miles.

During a recent extended flight the maximum error in position line was as much as 34 miles obtained from the mean of six observations, and the minimum error was five miles from the mean of four observations. The variation was due to the difference in atmospheric conditions on different days, the bad results being obtained on extremely bumpy days.

These tests were carried out in an aeroplane, and better results may be expected in an airship owing to the slower movement.

Many other designs of sextants involving the use of bubble horizons and reflected back and front horizons have been used, but their low degree of accuracy and disadvantages in design have led to their elimination.

Instruments for the rapid solution of the spherical triangle by means of plotted curves and graphical representation of formulæ have been tried, amongst which may be mentioned the Baker Navigating Machine, the Veater Diagram and the d'Ocagne Nonogram. These, however, have not given the high degree of accuracy desired under all circumstances, but were admirable as a stop gap.

The Bygrave Slide Rule has given remarkably good results and is rapid in solution. It consists of two cylindrical concentric scales—one a cosine scale and the other a tangent scale, and by dividing the spherical triangle into two right-angled triangles the zenith distance and azimuth can be computed.

Directional Wireless.

The use of directional wireless will no doubt play an important part in the

navigation of airships in the future, and even at the present time forms a means of checking a D.R. position or a fix, but owing to the atmospheric errors that cannot be calculated or allowed for, and the difficulty of always obtaining a good fix, it should only be looked upon as an important aid and not a substitute for other forms of navigation. A good pilot should use every method available to check his position, however accurate any one of them may appear to be.

Conclusion.

I have endeavoured to put before you the difficulties encountered in airship piloting, and the methods employed to overcome these difficulties. I have tried to show you that an airship is not a fine weather craft, and that with adequate ground organisation there is no reason why it should not fly anywhere in the world under any conditions.

I have tried to indicate from the pilot's point of view the main point to be considered in the design of ships of increased size, namely, the increase of speed, both to enable good regular flights to be made under all weather conditions and to reduce the difficulties from superheating.

I have dealt entirely with the ship in the air, and leave it to someone else to discuss the ground organisation, one of the chief features of which is airship mooring.

This mooring is now an accomplished fact and only wants developing to make it of practical value, and I hope I have shown that, as soon as mooring of airships has been developed, the airship for long-distance regular schedule flights is a sound practical proposition.

APPENDIX A.

THE EFFECT ON THE CHARACTERISTICS OF FLIGHT IN THE VERTICAL PLANE OF A DIFFERENCE BETWEEN THE WEIGHT AND BUOYANCY OF AN AIRSHIP.

Referring to diagram 1 :—

R_1, R_2, etc., represent direction of the resultant wind force on a ship, corresponding to inclinations of the relative wind to the axis of the hull, α_1, α_2, etc. The angle ψ and the distance x measured along the axis from the centre of buoyancy, define the line of action of R. x will be considered positive when measured from the C.B. towards the nose.

Diagram 2 indicates the effect of an inclination of the control planes.

The conventions of sign adopted are shown on diagram 4.

In a modern rigid airship x is comparatively large and positive when ϵ is zero and α is very small, and x decreases as α increases. x further decreases with increase of ϵ of the same sign as α.

ψ increases with α, at first being rapidly, and afterwards more slowly, as ψ approaches 90°.

ψ also increases with increase of ϵ of the same sign as α when α is small.

ψ may be expressed as f_1 (α, ϵ) and x may be expressed as f_2 (α, ϵ).

These functions may be determined from model experiments.

Case I.

Consider first the conditions for equilibrium in the vertical plane of an imaginary ship in which the centres of buoyancy and gravity coincide and the line of thrust passes through this common centre along the axis of the hull.

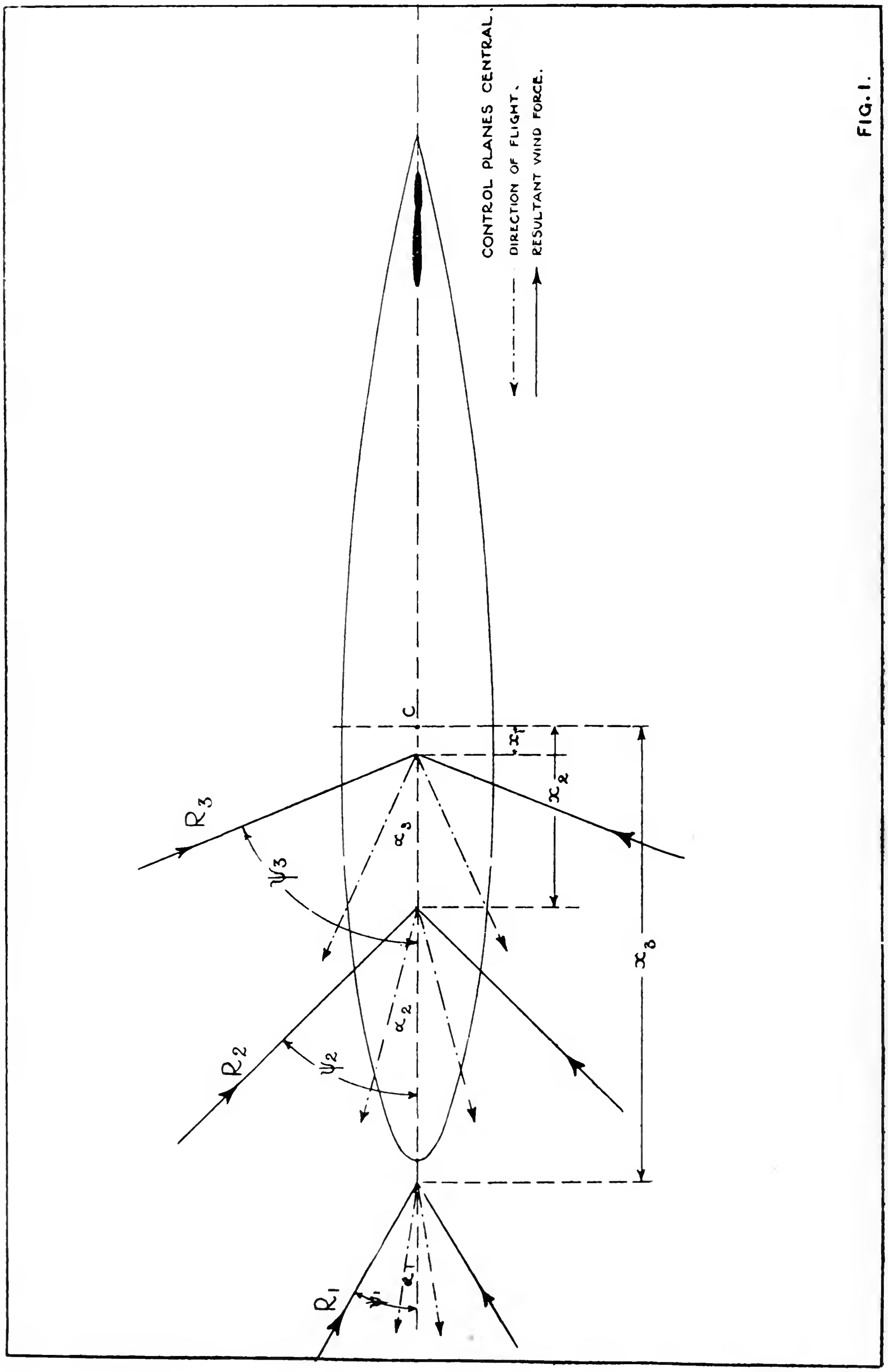

CONTROL PLANES CENTRAL.
DIRECTION OF FLIGHT.
RESULTANT WIND FORCE.
C
R3
R2
R1

FIG. 1.

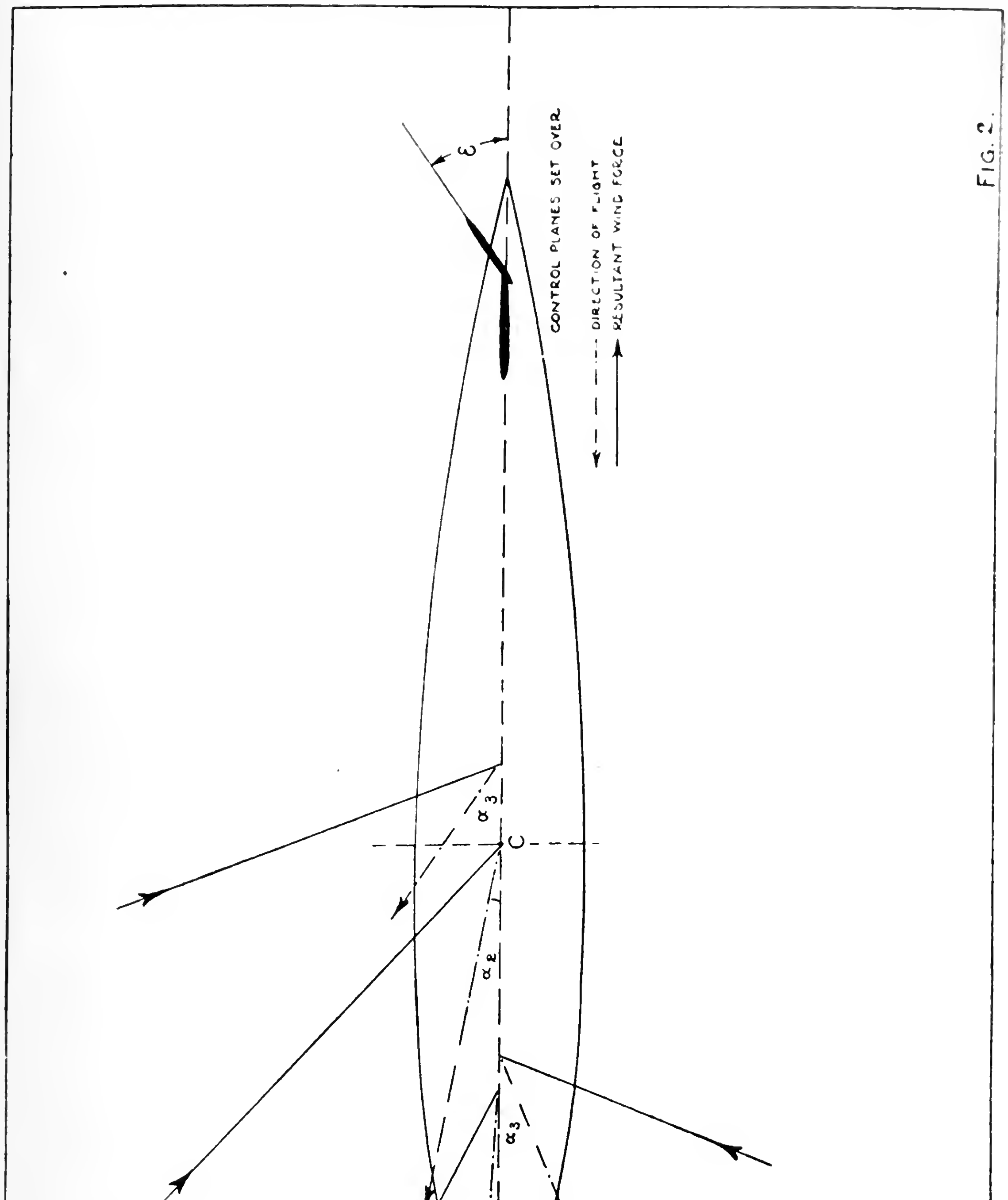

CONTROL PLANES SET OVER
DIRECTION OF FLIGHT
RESULTANT WIND FORCE
ε
C
α_3
α_2
α_1

FIG. 2.

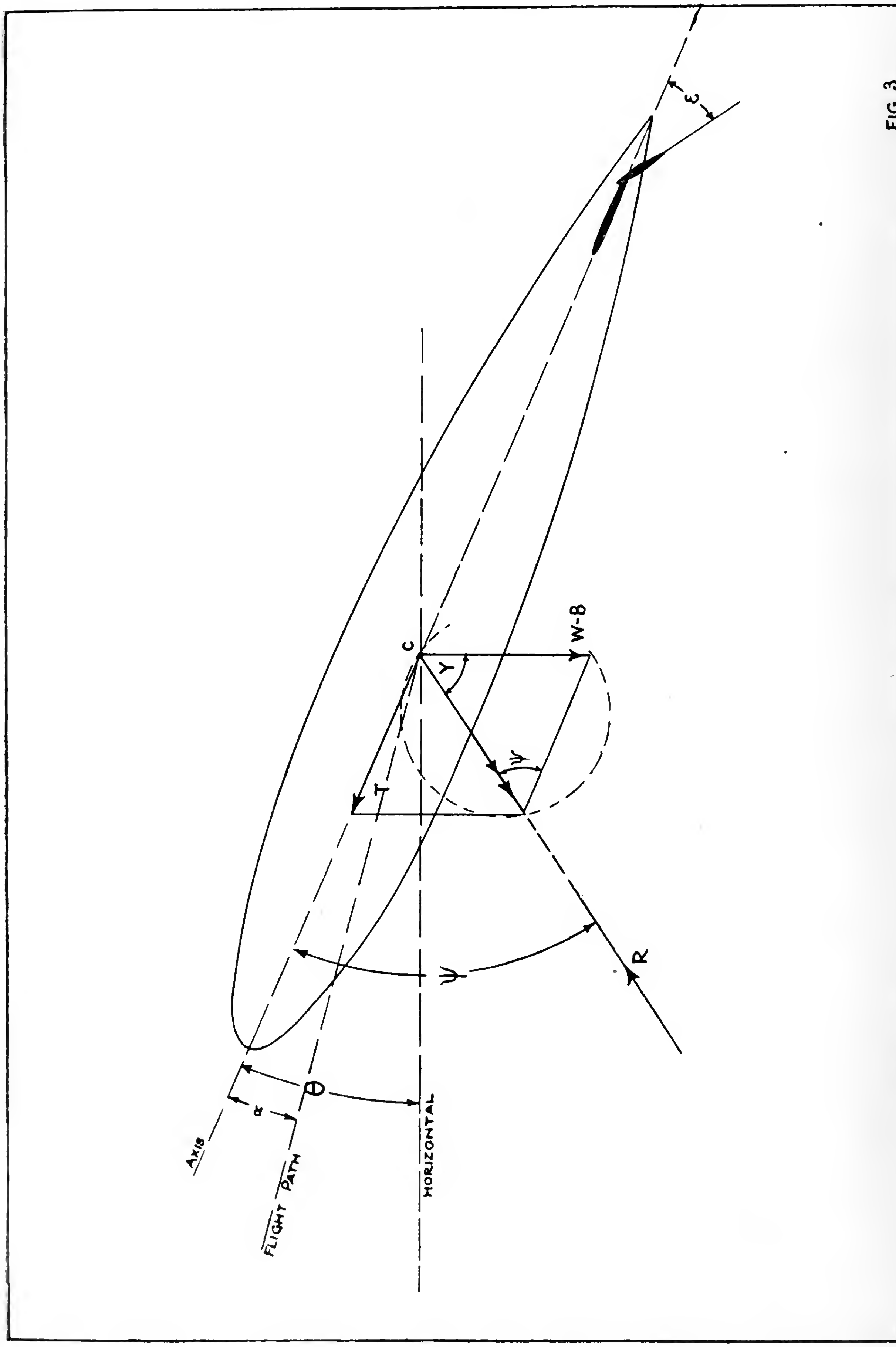


FIG. 3.

In diagram 3:—

W is the gross weight of the ship, including gas.
B is the weight of air displaced.
θ is the inclination of the axis of the hull to the horizontal.
T is the propeller thrust.
R, α, ψ, ϵ have the meanings assigned to them previously for diagrams 1 and 2.
γ is the angle between R and the vertical.

For equilibrium in rectilinear flight, the resultant of T and $W - B$ must be directly opposed to R.

Therefore

$$T/(W - B) = \sin\gamma/\sin\psi$$
$$= \cos\theta \cot\psi + \sin\theta$$
$$\text{since } \gamma = 90^\circ + \theta - \psi$$
$$\text{so that } \sin\gamma = \cos(\psi - \theta)$$

or

$$T/(W - B) = \cos\theta \cot f_1(\alpha, \epsilon) + \sin\theta \quad . \quad . \quad . \quad (1)$$
$$\text{and } x = f_2(\alpha, \epsilon) = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Hence for any given position of the control plane, ϵ, the values of α and ψ are determined by the relation (2) and the variation of the ratio $T/(W - B)$ can only be met by varying θ.

If the range over which ψ be varied by varying ϵ (equation (2) being satisfied) be relatively small (as in the present ships), it may be seen that the direction of flight, $\theta + \alpha$, is much dependent on the ratio of $T/(W - B)$.

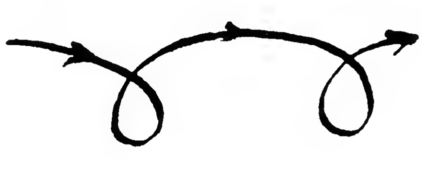
In diagram 3 a "heavy" ship is shown, *i.e.*, $W > B$. Suppose ϵ and $W - B$ constant, and consider variation of T.

Since ψ is constant, the vector representing the resultant of T and $W - B$ must terminate on the dotted circle. At low values of T the ship would descend. As the thrust is increased θ will increase until above a certain speed the ship will climb. (Similarly, if the ship were "light" it would then descend.)

As T approaches in magnitude to the diameter of the circle the ship will become less stable. There will be two possible values of θ when T is $> (W - B)$ but less than the diameter.

Finally, when T exceeds the diameter of the circle defined by $W - B$ and ψ, equilibrium will only be possible with a curved flight path thus

if "heavy," or



if "light."

The behaviour may be compared to that of an aeroplane having inherent longitudinal stability, the elevator being supposed fixed and the thrust varied.

If $W - B = 0$, the only *stable* flight path would be circular, as is true of flight in the horizontal plane, the component of R at right angles to the axis being balanced by the centrifugal force.

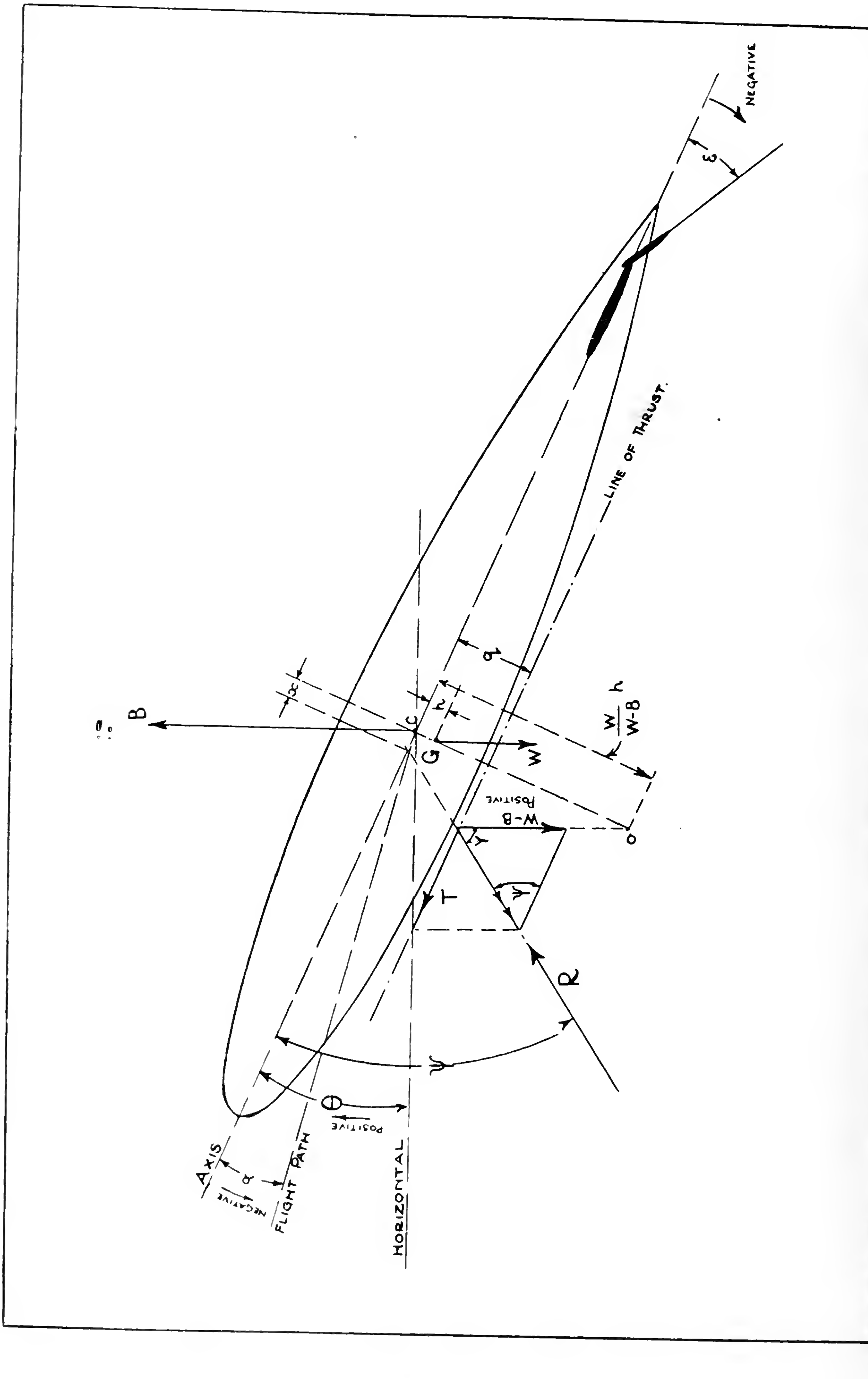

NEGATIVE
LINE OF THRUST.
B
W
G
C
W-B
POSITIVE
T
R
AXIS
NEGATIVE
FLIGHT PATH
POSITIVE
HORIZONTAL

FIG. 4.

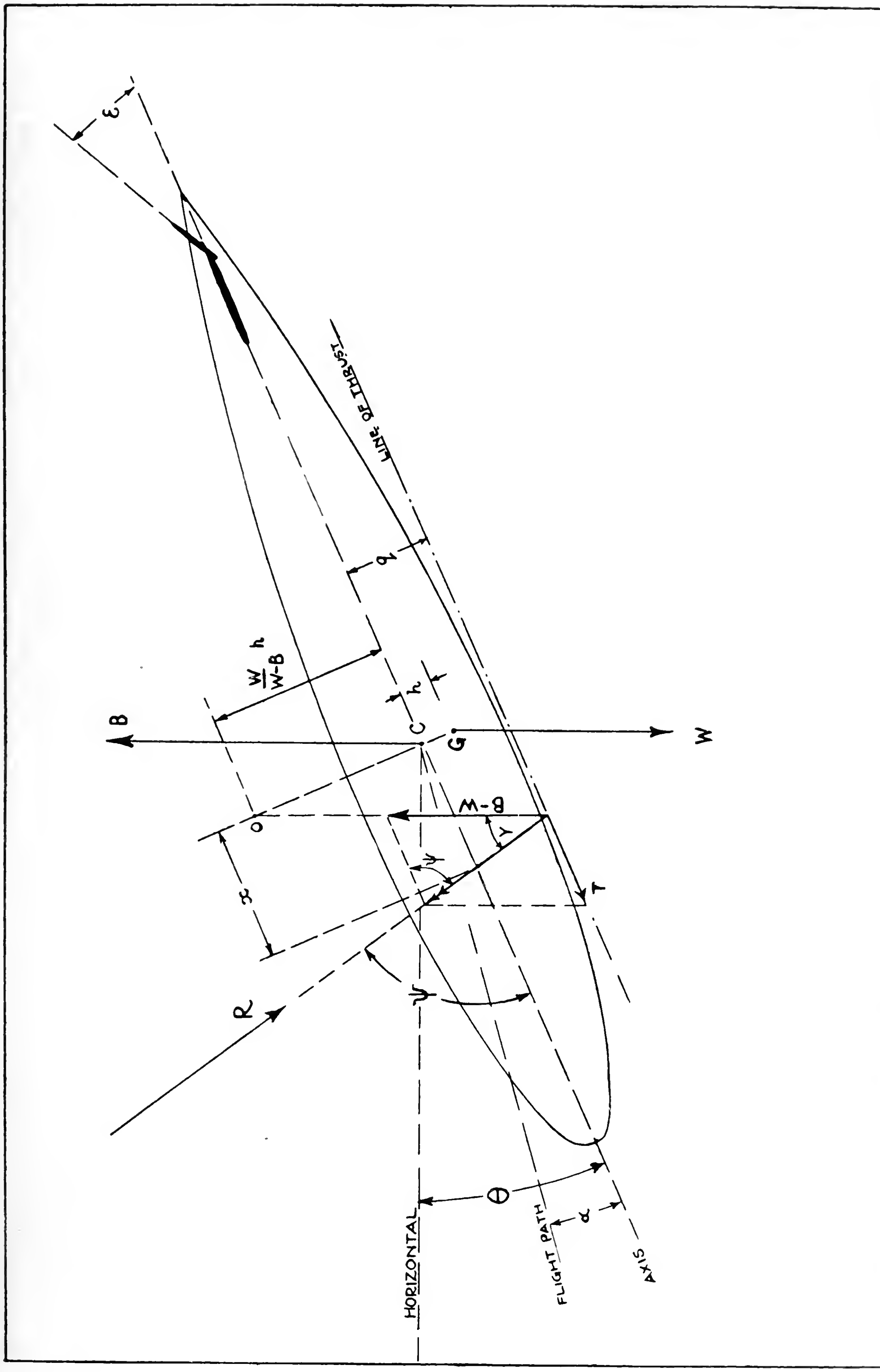

LINE OF THRUST
HORIZONTAL
FLIGHT PATH
AXIS
B
W
G
C
o
R
T
B-W
$\frac{W}{W-B}h$
h
a
x
ε
ψ
γ
θ
α

FIG. 5.

If $W - B$ vary, any given conditions will be obtained at the same value of $T/(W - B)$, so that, for instance, the maximum speed of horizontal flight (when "heavy" with elevator hard down, or when "light" with elevator hard up), or the speed at which flight becomes unstable, will be proportional to $\sqrt{\pm(W - B)}$.

It may be noted that at the maximum speed of straight flight, when T is a diameter of the dotted circle, the angle γ is 90°, R is horizontal, and the flight path is inclined to the horizontal.

It should be mentioned that the case where $f_2\ (\alpha, \epsilon)$ is always zero or negative represents larger planes than can be fitted in practice, and has not been considered. Such a ship would be stable at all speeds.

Case II.

Diagrams 4 and 5 more nearly represent the case of an actual ship, in which:

h is the distance of the centre of gravity below the centre of buoyancy C.

q is the distance of the line of thrust below the axis of the hull.

Horizontal static trim is assumed.

The conditions of equilibrium in straight flight may be seen to be, as before,

$$\begin{aligned} T/(W - B) &= \cos\theta \cot\psi + \sin\theta \\ &= \cos\theta \cot f_1\ (\alpha, \epsilon) + \sin\theta \qquad (1) \end{aligned}$$

also,

$$\begin{aligned} f_2\ (\alpha, \epsilon) = x &= Wh \tan\theta/(W - B) - q\ (\tan\theta + \cot\psi) \\ &= W/(W - B) - q\ (\tan\theta + \cot f_1\ (\alpha, \epsilon)\ ) \qquad (2) \end{aligned}$$

In practice, when α and ϵ are small, as in normal flight, x has a considerable positive value.

If θ is small and of the same sign as $W - B$, as in normal flight, a large value of h gives a large (numerical) value of x/θ. This enables the conditions of equilibrium to be satisfied for a large range of speed and buoyancy, with small change of θ. This increases the maximum speed of horizontal flight, but decreases manœuvrability at low speed.

The term $q\ (\tan\theta + \cot f_1\ (\alpha, \epsilon)\ )$ changes sign with α under most conditions. Increase of q, therefore, increases x/θ when "light" and reduces it when "heavy" under normal conditions of flight, as above.

It, therefore, appears that h and q should both be kept small, particularly the latter. h and q have both relatively decreased in modern ships as compared with older types.

When $W - B$ is large x/θ becomes small and the conditions of equilibrium approach to those of Case I. Equation (1) then shows that ability to maintain θ, or $\theta + \alpha$ constant, over a wide range of speed and, therefore, of T, requires large variation of $f_1\ (\alpha, \epsilon)$, and/or of $f_2\ (\alpha, \epsilon)$ with ϵ, and, therefore, large control planes.

A value of $(W - B)/W$ of 4 or 5 per cent. is not exceptional.

This is of the same order as the thrust at full speed and in modern ships produces a maximum limit to the speed of horizontal flight well below full speed, the behaviour of the ship approximating to that deduced for Case I.

This limitation may be reduced, or removed, as has been shown, by increasing the size of the control planes. This involves increased weight and constructional difficulties.

The shape of the hull also largely affects the functions $f_1\ (\alpha, \epsilon)$ and $f_2\ (\alpha, \epsilon)$, but unfortunately shapes so far discovered which are considerably better in this respect have considerably higher resistance when $\alpha = 0$. A compromise in hull form may be found to be advantageous. It must be remembered that under

average conditions of flight a is not zero, and, consequently, the form which has the lowest resistance when $a = 0$ may not be the best.

Considering similar strips of varying linear dimension, L, at speed V.

$$R \text{ and } T \text{ vary as } L^2V^2.$$
$$W - B \text{ and } W \text{ vary as } L^3.$$

Therefore similar strips of varying size will behave in the same manner at speeds proportional to $\sqrt{L}$.

Flight-Lieutenant F. L. C. Butcher, R.A.F., delivered the following lecture:

AIRSHIP MOORING AND HANDLING.

Introductory Remarks.

At the present time, although an airship can navigate in very strong winds, when in the air, great difficulty is experienced in handling her on the ground, and many opportunities of flying are missed for this reason.

Although it is possible to leave the sheds in doubtful weather, there is always the chance that if the wind freshens considerably, she may be forced to remain out several days, or that serious damage may be done if an attempt is made to land and take her into the shed.

It is, therefore, essential to the success of airships in the future that the mooring problem must be solved to enable them to be quite as independent of their sheds as a sea-going liner is of her dry dock. Not only would a satisfactory system of mooring enable airships to leave the ground and land in far stronger winds than at present, but it would considerably reduce the number of men required for a landing party.

This problem is so complex that it is impossible for me to go into details in the time at my disposal, but I will endeavour to explain the various methods which have been tried in this country with their advantages and disadvantages.

Handling by Means of Landing Party and Windscreens.

When a large airship lands the fore guys are caught by the landing party detailed for them and run out at right angles to the centre line of the ship, thus ensuring that her bows are kept pointing "up wind." The ship is hauled down until the cars are in the hands of the car parties, who keep them from dragging along the ground or rising too far off it.

After ballasting up to ensure sufficient lightness for handling, the ship is walked towards the doors of the shed by the parties on the fore handling guys and bow rope.

I will take as an example the most difficult case usually experienced in housing a large rigid (*i.e.*, a wind blowing across the direction of the sheds), and explain the method employed to get the ship in. The bows are manœuvred into a position as far to windward of the doors as the windscreens allow (see Fig. 1), and the stern is walked towards the shed by the men on the after guys. The bows are eased away from the wind, but kept well in hand and not allowed to drift to leeward of the centre line of the shed. When the ship is lying in the position shown in Fig. 2, she is walked bodily astern, the bows being allowed to drift towards the centre line of the shed as the stern moves further into the shed.

If, in the course of taking the ship in, she drifts dangerously near the side of the shed, it has been found that she can be rushed out again more easily when this method is employed than if she is taken in bows first.

When the wind is blowing "up and down" the sheds, the ship may be taken in at either end of the shed, and a considerable difference of opinion exists as to

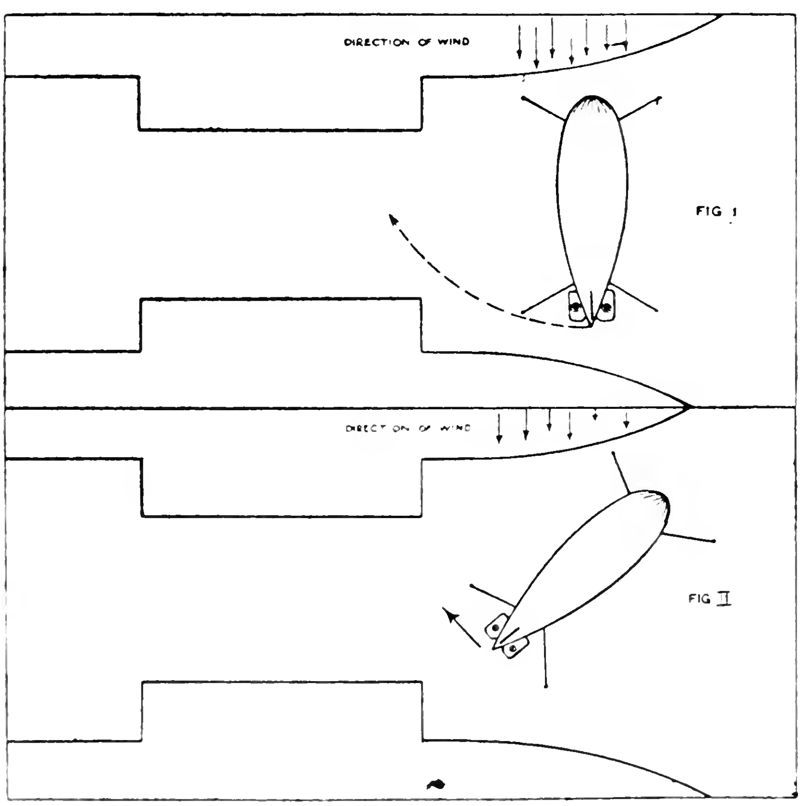
which is the better method. If the ship is taken in through the leeward doors, handling is rendered difficult owing to the bumps and eddies caused by the shed, but in the event of the ship "taking charge," she is more likely to drift clear than if the windward doors were used. By opening the windward doors slightly, and allowing a current of air to blow through the shed, the state of the air on the leeward side is improved to a great extent.

In strong winds it is found that the ship rises and falls very rapidly owing to gusts and the downward component of the forces on the guys. This movement is at present checked by the parties on the cars, but in larger ships the cars will be so small compared to the bulk of the ship that handling frames of light structure extending from the keel girders to the same level as the bottom of the cars will have to be used. These frames have been in use in Germany for some years, and have been tried and found satisfactory in this country.

The above description gives an idea of the difficulties of housing a large airship, and shows the necessity of advancement in this direction, either by mechanical handling or by mooring the ship out when the wind is strong.

The Advantages and Disadvantages of Windscreens.

The windscreens used in this country are of two distinct types, the solid windscreen, which allows no air to pass through it, and the screen made out of expanded metal which reduces the velocity of the air passing through it by about 80 per cent. The protection of the solid screen is felt in winds of low velocity, especially light cross winds, and a ship which is being taken into the shed may be relieved of considerable strain by keeping her well under the lee of the screen until very close to the mouth of the shed.



In strong winds, the air, after being forced up out of its path by the screen, naturally descends as soon as it can, causing a suction and a bad down current some 15 or 20 yards to leeward.

This makes airship handling difficult under certain conditions. Expanded metal screens are a distinct improvement on the type described above as they do

not cause such gusts and differences of pressure, and a ship can be housed in a steady wind of about 20 per cent. of the outside ground wind.

The use of windscreens has been discontinued, as, in the case of large airship sheds, they would have to be placed so far apart owing to the large manœuvring space required by a modern airship that they would be practically useless.

In Germany windscreens are not used at all, and mechanical handling by means of trollies and rails is invariably employed.

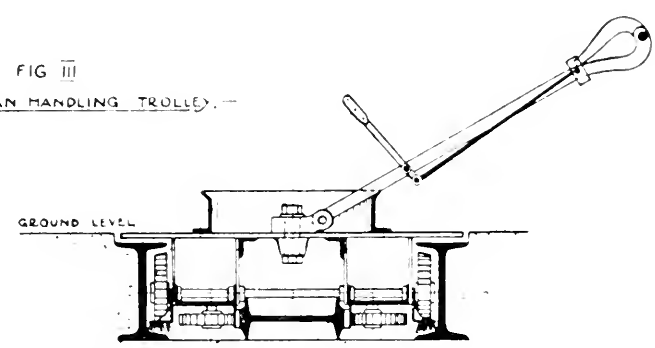
The following is a short description of their method.

Mechanical Handling.

In each double shed four sets of rails are laid down and extend to a distance of about 1,000ft., as shown in Fig. 4. The rails are of I-section and the set consists of three, one horizontal and two vertical, Fig. 3. The trollies are fitted with four wheels, running inside two vertical rails which take the lifting and upsetting forces, and six wheels running on the horizontal rail to take the side thrust. All wheels are fitted with roller bearings, and brushes are placed both in front and behind the trolleys to keep the rails clear, thus ensuring smooth running.

FIG III

— GERMAN HANDLING TROLLEY. —



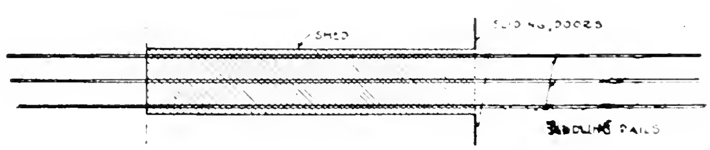


FIG IV

— ARRANGEMENT OF RAILS IN GERMAN SHEDS —

To take a ship in by this system, the following method is employed :—

The ship is landed as near as possible to the end of the rails and walked up to them, rope tackles are led from two trolleys (one on each rail) to the mooring point and hauled taut. The ship is then walked towards the shed by parties of men on the bow hauling rope and fore guys until the stern can be hauled up to the rails and secured in the same way as the bows.

Each trolley is fitted with ropes which are manned by not more than eight men who keep them abreast of the ship. The rest of the handling party are employed on the bow hauling rope, fore guys, and underneath the car and handling frames to prevent the cars from bumping along the ground.

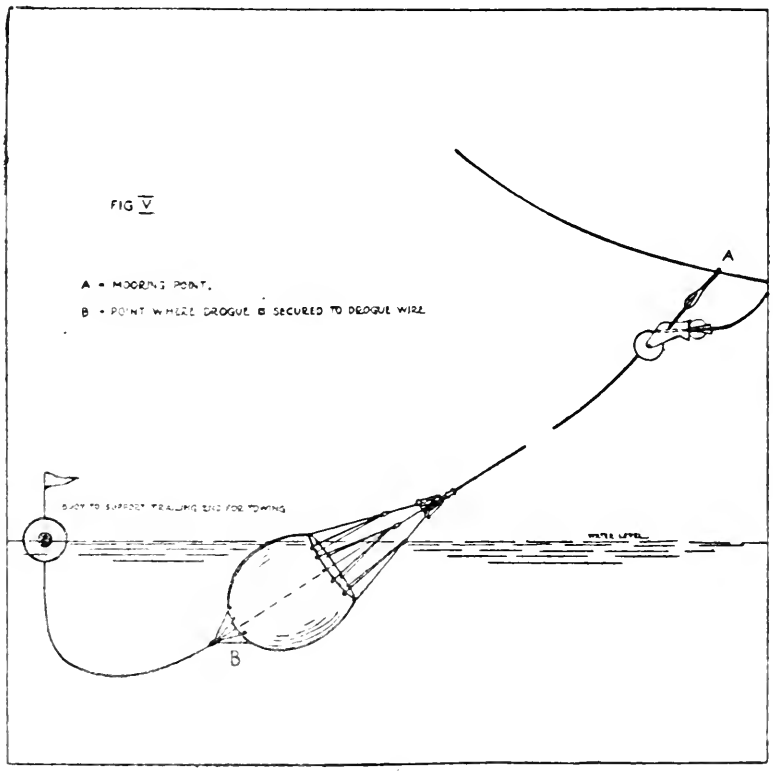
The ship is taken out of the shed in the same way until she is clear, then the aft guys are manned, the tackles eased off, and the stern allowed to swing in

the direction of the wind. The bows are hauled out to the end of the rails, by which time the fore guys can be manned and the bow tackles eased off.

This method of handling is very simple and undoubtedly superior to our method of handling parties and windscreens; it enables the ships to be taken out in cross winds up to 25 m.p.h., without risk of damage, with two-thirds of the landing party usually employed.

In 1917 and 1918 experiments with tractors were made with the object of reducing the landing party required to handle a rigid airship. Each fore guy was secured to a tractor, and the ship was towed towards the shed. This scheme, however, was given up owing to the severe shocks transmitted to the structure by the tractors rising and falling over bumps on the aerodrome, the noise of their engines, and their inability to manœuvre quickly.

On one occasion it was necessary to take R.9 into the shed at Howden in a cross wind of about 30 miles per hour, and a tractor was used to tow the ship forward. In the course of taking her in she was damaged considerably against the side of the shed, but had not the tractor been used she would have, in all probability, broken away.



Mooring Over the Sea.

When airships are patrolling or carrying out prolonged flights over the sea there is always the possibility that the wind may increase to such an extent that the ship runs out of petrol before making her base; in this case the only thing to be done is to drop a sea anchor or drogue and signal to surface craft for assistance and a tow to the nearest place where petrol is obtainable.

The following is a short description of the tackle usually fitted in rigids for riding to a drogue. The general arrangement can be followed by referring to Fig. 5.

The drogue itself is made out of stout canvas roughly in the shape of a bucket, strengthened round the rim by roping, and eyeletted to take the twelve bridles which, in groups of three, are hooked in the jaws of the drogue slip. The drogue wire is continuous from the bows of the ship through the slip and drogue, which are fitted some 30 to 40 feet from the end, thus leaving sufficient wire trailing behind to be picked up and secured by the towing ship before the drogue is spilled.

The slip (see Fig. 6), which was especially designed for this purpose, is operated by the impact of a weight sliding down the drogue wire, and can be described as follows:—The bridles for the drogue are held by four hooks pivoted on the body of the slip, and which in the normal position are guarded, as shown in the figure, to prevent the bridles from becoming unhooked when the drogue is dropped.

These hooks are held in position by extensions or arms with hooked tongues fitting over the rim of a cup sliding on the central guide. The cup is held up by a strong spring and has a projecting top which is struck when the weight is released and slides down the wire. When the weight hits this projection the cup is forced down against the spring, thus releasing the arms, which immediately fly outwards, due to the strain on the hooks, and the bridles are slipped. It has been found that an eight-ounce weight will spill the drogue when dropped from about 75ft., though the slip is several feet under water.

The extension of the drogue wire passes through the bottom of the drogue, which is secured to it at this point, so that when the bridles are slipped the drogue turns inside out, enabling it to be drawn out of the water.

FIG. VI.

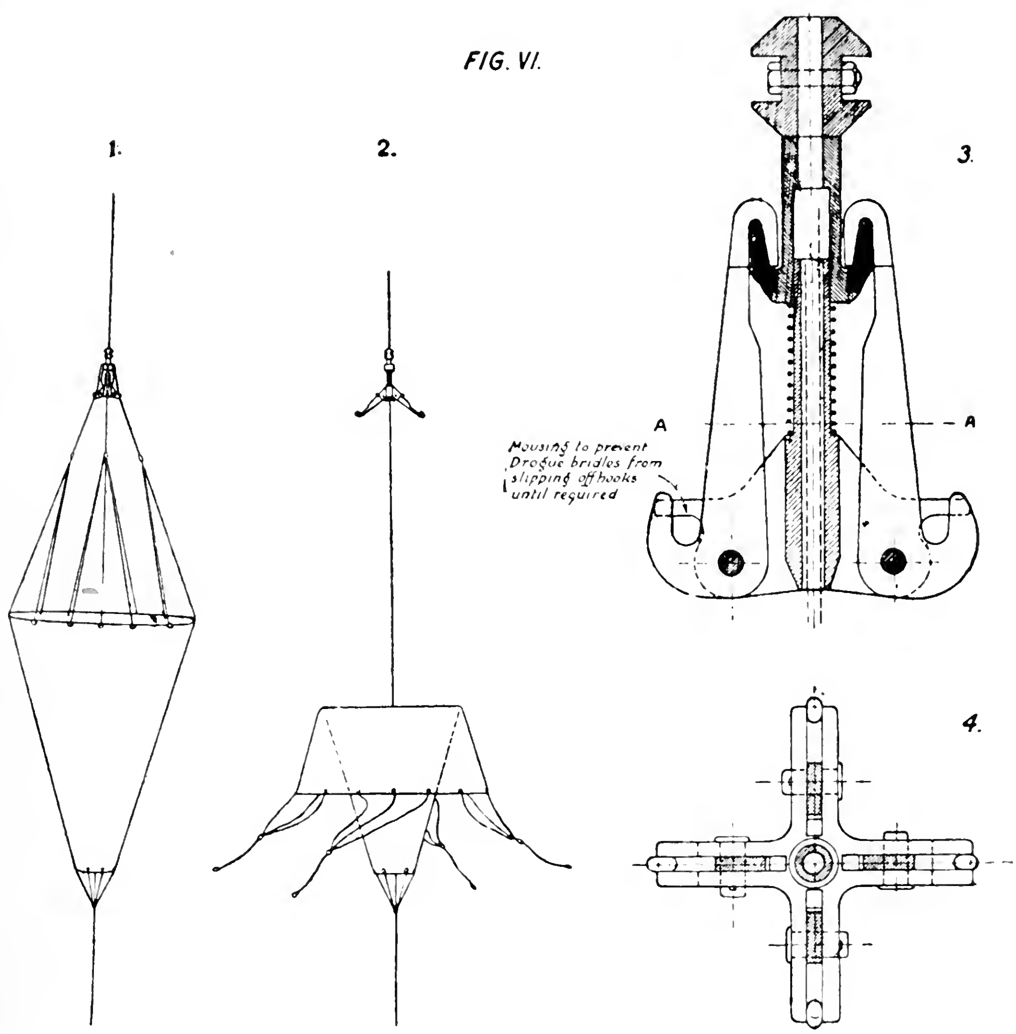


FIG. VI.—*Arrangement of improved S.O.B. Slip.* 1, *Drogue in position for use;* 2, *Drogue "slipped"*; 3, *Vertical section;* 4, *Horizontal section through A-A.*

This fitting was found necessary owing to the fact that the large drogues used hold from four to five tons of water, and would either have to be cut adrift or lifted bodily out of the water, which is inadvisable owing to the alteration of trim and waste of ballast necessitated.

The pull in the drogue wire is transmitted to the ship by means of a ball-stopper wedged on to the wire, which takes up against a block secured to the mooring point with a wire strop seen in Fig. 7.

As soon as the pilot decides to ride to a drogue, the required length of wire is reeled off the drum and the ball-stopper wedged securely at a distance from the drogue corresponding to the height at which it is desired to ride, allowing a margin for the sag in the wire. The wire is paid out in a loop from the bows, keeping the drogue still in the ship, until the stopper comes up against the block attached to the mooring point.

The drogue is dropped when the ship is about 100 to 150 feet above the water and carrying as little way as possible. As the ship drifts with the wind the drogue, by being towed through the water, fills, thus keeping the bows of the ship into the wind.

The drogue, of course, does not hold the ship stationary over the water, but retards its drift to such an extent that even in strong winds the drogue wire can be picked up by surface craft and made fast for towing.

Experiments were carried out by R.9 and R.23 over the Wash with drogues in 1918, and it was found that it was only advisable to ride to a drogue in cases of emergency, until some satisfactory arrangement was made to enable the ballast bags to be filled fast enough to counteract the lightness caused by superheating. The airships in both cases were successfully taken in tow by a motor boat, and the drogue wire secured to a buoy, thus showing that in the case of a broken-down airship at sea it is not a difficult matter to salve her.

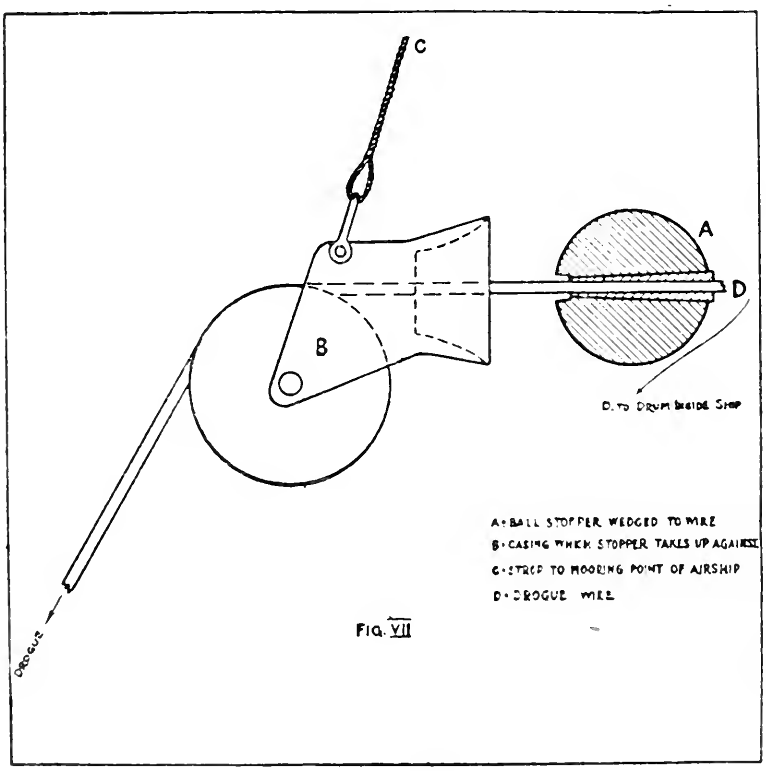


FIG. VII

This brings up the question of long distance airship towing by surface craft.

In July, 1919, N.S.7 was towed from Newcastle to Southend by H.M.S. "Furious," steaming at 17 knots, and although the tow-rope parted once owing to a faulty splice, a line was lowered and the rope hauled up and made fast again. In winds of over 30 miles per hour the airship kited when H.M.S. "Furious" was not under weigh, but it was possible to counteract this by running one engine slowly.

This series of experiments show that it is possible for an airship to work in

conjunction with surface craft at a considerable distance from her base, and if the parent ship was provided with fuel and gas, the airship could operate for several weeks.

Mooring Over Land.

This subject can be divided into two parts, Mooring by Wires and Mooring to a Mast.

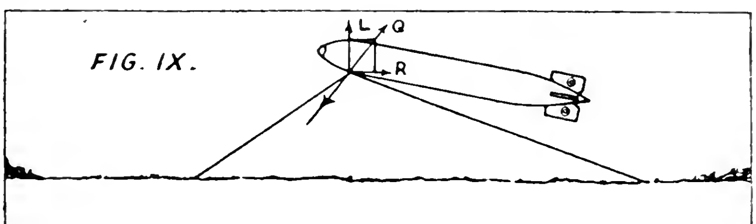
Mooring by Wires.

The first system of mooring an airship in this country was known as the Usborne system, and in this case the ship was secured to one point on the ground by two wires, one vertical from the mooring point and one made fast to the car. The ship was steadied by wire guys led aft from the mooring point at an angle of about 120°, and secured to posts.

Several early Non-Rigids were moored by this system in the beginning of the war, but were not strong enough to stand high winds, and therefore experiments on these lines were discontinued.

Three-Wire Mooring System.

The incident which led to the reconsideration of mooring an airship by wires occurred in 1917, when R9 returned from patrol short of fuel with a strong wind blowing. It was decided to hold her out on the landing ground until the wind



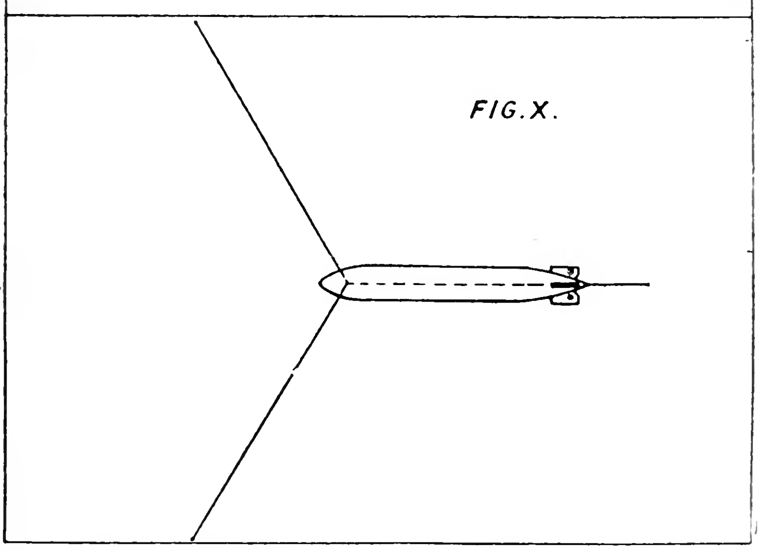


FIG. IX.—*Diagram of forces in three-wire system.*
FIG. X.—*Diagram of open hawse position, Mark I.*

moderated, but such difficulty was experienced in keeping her steady that the captain secured the mooring point to three bollards which formed a triangle on the ground. Owing to the satisfactory results obtained, further experiments were carried out, from which the three-wire mooring was developed.

An airship was moored to three wires secured to posts or bollards sunk in the ground at the apices of an equilateral triangle, and spliced to a swivel at the mooring point of the ship.

The forces acting on a rigid airship moored to this system may now be considered:—

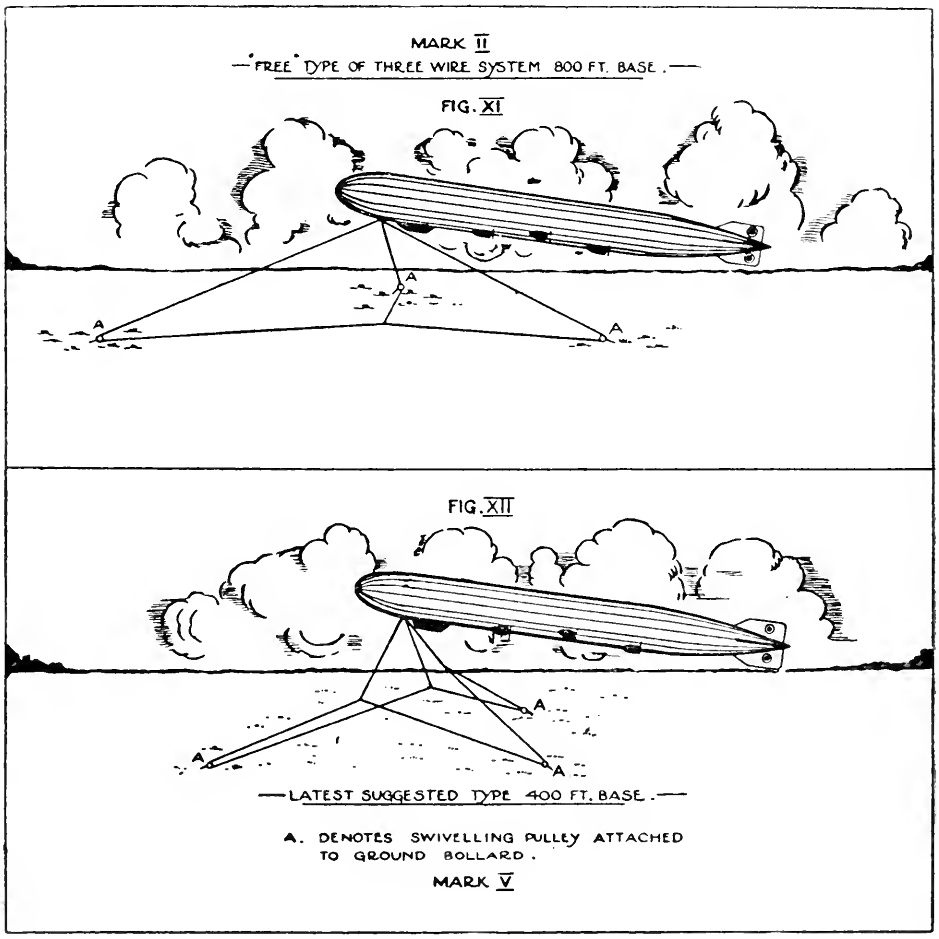
It was required to maintain the ship at an altitude of 200ft., pitched slightly down by the stern, as shown in Fig. 9.

The forces acting on the ship at the mooring point are as follows:—

L = The vertical lifting force composed of the static lift due to the buoyancy of the ship and the dynamic. lift due to the angle at which the ship is pitched.

R = The backward force caused by the wind pressure on the hull and cars.

By completing the parallelogram of forces, the resultant force Q was found, and from this the angle of the wire was calculated to give the necessary equal and opposite force when the ship was lying in the "open hawse" position, shown in Fig. 10.



It was found that the ship, when moored to this system, was driven backwards and downwards by gusts, causing the leeward wires to slacken and tighten up with a sharp jerk which strained the structure round the mooring point.

Further experiments were carried out in a wind tunnel, with the result that it was decided to moor an airship to a modified system (see Fig. 11). The same bollards were used as in the last trials, but the wires were spliced into a central ring and led through blocks on the bollards to a swivel at the mooring point of the ship 200ft. above the ground. The ring, therefore, was free to move within the triangle formed by the posts, and in this way the wires were kept taut the whole time.

R26, an obsolete ship due for deletion, was strengthened in the bows by additional diagonal wiring extending over frames two and three, and when this

was completed, was walked out of the shed and secured to the swivel on the mooring system. The trim of the ship was altered until the forward part was sufficiently light to lift the weight of the wires, while the tail was kept in equilibrium and was allowed to rise until the wires were taut.

The ship remained out for ten days, and the following experience was gained:

During the first six days, the winds were light, and did not exceed 10—15 miles per hour; the nights were very cold, followed by hot sun, and, owing to the slow and inadequate means of transferring ballast to the ship, she became very light, due to superheating, and on two occasions the stern rose until the ship was riding at an angle of 25 degrees.

A kite balloon winch was used for hoisting ballast up to the ship, and ropes were hung from the four after-handling guys on which sandbags were secured as compensating ballast. Difficulty was experienced with this compensating ballast, as each time the stern passed over one of the mooring wires the ballast had to be unhooked, the rope passed over the wire, and the ballast hooked on again the other side; this required a party of about six men standing by, and in gusty weather caused a lot of work and supervision.

On the ninth day the wind got up from the East and gradually increased to 35 miles per hour. Throughout this period the ship rode steadily, yawing slightly until the rudders were lashed with about three degrees of port helm on. This had the effect of reducing the tendency to yaw by keeping the wind more on one side than the other; consequently the ring on the ground shifted about 100ft. ahead and 50ft. to port of the central position, but moved back and remained fairly steady between this point and the centre. The friction of the wires moving across the ground damped the yawing motion of the ship considerably.

Heavy rain fell in the evening, and owing to the porous condition of the outer cover, the ship collected about two tons of water, but did not seem to get any heavier in spite of the continuous rain.

At midnight the wind backed to N.E. and rose to 35 miles per hour with gusts to 45 miles per hour, changing the direction of the ship to midway between two wires and shifting the ring to a position 60ft. ahead and 20ft. to port of the centre. The yawing motion continued, but the ship showed no tendency to move forward or aft when struck by gusts, excepting on one occasion when the wind suddenly shifted a point for a few seconds and drove the ship very near the ground.

Early next morning snow fell and forced the ship down to the ground, as R26 was an obsolete ship and had not enough disposal lift to counteract it. She lay steady on the ground, rolling slightly from side to side in a wind of 35 miles per hour, and a good deal of structural damage was done.

In the afternoon the snow melted, and when the cars were taken off, the ship rose and remained steady throughout the night. She was taken into the shed next day owing to the damage done while on the ground, and on examination it was found that the hull in the vicinity of the mooring point was not strained.

The conclusions drawn from this experiment were:—

(1) That the ship rides best at an angle of 4 to 5 degrees down by the stern with about the same number of degrees of helm on in order to keep the bows slightly off the wind.

(2) That a quick system of filling the ship with ballast is absolutely essential to prevent the stern from rising to a dangerous angle when superheating.

(3) That a ship could ride out any ordinary blow when moored out to the three-wire system, provided that the mooring point is structurally strong.

(4) That a ship with a reasonable lift must be used so that the necessary reserve of ballast can be carried to meet adverse changes in weather.

(5) That a ship returning to base is usually short of ballast, and therefore gassing and ballasting arrangements must be provided.

The advantage of this method is that it can be prepared in a very short while, at a small cost, and is effective in an emergency. Moorings of this type could be placed at points on an airship route in case a ship is unable to get to the next mooring mast owing to engines failing in a strong wind.

The disadvantages are :—

(1) The petrol and water hose have to be disconnected and the turns taken out of them when the ship swings, as a hollow swivel was found to be too heavy for use.

(2) The difficulty of changing crews and taking in supplies.

(3) The large space of level ground required for this system, owing to the size of triangle necessary to keep the ship steady at the "open hawse" position.

R.34 at Mineola.

R.34 was moored to this system after landing from her trans-Atlantic flight at Mineola, behaving well and riding steadily.

On one occasion, however, after a heavy rainstorm she came down to the ground, but rose again when gassed. On the following morning when the sun came out, the rain dried off and the ship superheated so quickly that ballast could not be taken on board fast enough with the arrangements available. The casting at the mooring point broke, but luckily held the ship until she could be hauled down and more water taken aboard.

R.34 remained there for four days and rode out some very gusty weather, thus demonstrating the usefulness of the three-wire mooring system in the case of an emergency.

Since that date wind-tunnel experiments resulting in two modifications of this system have been made. In the first, the three wires, instead of being spliced to a ring, are brought to the three corners of a parallelogram; the fourth corner is held by another wire secured to a bollard. It is claimed that by this method the movement of the wires will be damped to a considerable extent without causing jerks on the structure of the ship (Fig. 13).

The second method, shown in Fig. 12, has been developed because, in modern streamline ships, wires from the mooring point to a triangle of 800ft. base would foul the fore-car when the ship swung. The base in this case is 400ft., and theoretically better results will be obtained than with an 800ft. base, but neither of these modifications have been tried on a full scale.

Other Methods.

Occasionally during the war non-rigid airships were unable to return to base owing to engine breakdowns in strong winds. In the case of small airships, such as the S.S. type, they were landed as free balloons and deflated without much damage.

In December, 1917, however, a North Sea type of 360,000 cubic feet capacity was caught while at sea in a wind of 35-40 m.p.h. with one engine broken down. The coast was reached eventually, but as no headway could be made with one engine against the wind the captain decided to land, and endeavour to moor the ship out behind a hedge until the wind moderated sufficiently to enable him to fly back to base.

The ship was flown down to within a few feet of the ground, head to wind, the second officer and second coxswain jumped out, caught the fore guys and secured them to the hedge. These kept the ship steady in the wind for several hours, but eventually the port guy broke and deflation was resorted to.

In the summer of 1918 a great number of S.S. Zero type airships were used to escort merchant convoys as a protection against submarines, and, owing to the small shed accommodation available, were moored out at sub-stations along the coast. A tall wood bordering on a good landing field was selected as a site for the station, and a clearing made in the centre of it sufficiently large to hold the ship; this clearing was connected to the landing field by a lane through which the ship could be walked.

To moor a ship in the clearing the guys were taken out at right angles to the centre line and secured to trees. Two additional guys were fitted to patches on the top of the envelope to prevent excessive rolling and made fast in the same manner. The car was ballasted down until it rested on the ground, and the tail held down by a rope to weights on the ground.

This method was in use at all small stations situated near the coast, and in many cases winds of 40-50 m.p.h. were weathered without damage to the ships.

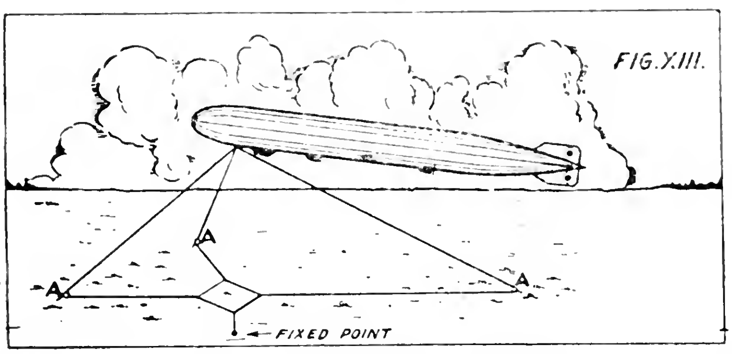


Fig. XIII.—*Modified "free" three-wire system, 800ft. base, Mark IV.*
(A) Denotes swivelling pulley attached to ground bollard.

Regular patrols were carried out from these mooring stations, and when repairs were needed the ship was flown back to base and another substituted.

Mooring to a Mast.

Attempts were made to moor out non-rigid airships to a mast designed at Farnborough and erected at Kingsnorth. The top of the mast revolved and consisted of a hollow cone, the base of which was padded to fit round the nose of the airship. This cone was pivoted at its apex, and a balancing weight was fitted on a short arm on the opposite side of the pivot. The nose of the ship was strengthened and a mooring wire spliced into it.

When it was necessary to moor out an airship the nose was brought as near as possible to the cone by the landing party, and the mooring wire led through the padded ring over a block at the apex of the cone and down to a small winch, which, when operated, hauled the nose of the ship into the cone. This method proved satisfactory in light or steady winds, but in gusty weather, when the movement of the ship was rapid, a bending stress was set up in the fabric just behind the ring; this wrinkled one side of the nose and put a corresponding tension on the other, which tore the fabric after a short while.

The reason for this was the fact that a few feet of the nose were held inside the cone and that the point of attachment of the ship was not directly above the pivot of the top of the mast.

The cone was done away with, and a ship was moored directly to the top of

the mast, but it was found that the fabric was not strong enough to stand the force of the wind on the ship. Consequently an axial spar, stayed to the after ends of the nose stiffeners and projecting through the nose, was fitted to a ship, and the spar secured to the top of the mast. This system was tried out with satisfactory results until the spar broke, and the experiments were discontinued for the time being.

Trials were also carried out at Barrow in 1918 with a small non-rigid moored to the top of a mast and secured to it at the point where the fore guys are fitted, but the ship rolled badly and the following system was evolved from it.

Barrow Mast Mooring System for Non-Rigids.

In this case the ship is attached at two points on opposite sides of the nose to the two sides of a crutch mounted on a vertical mast; this crutch is built solid with the mast, which is free to turn a ball and socket bearing at its base, while it is supported just below the crutch by six guys fastened to one part of a roller bearing, the other part being solid with the mast.

The envelope is fitted with ring patches at the points of attachment consisting of a circular steel plate with a ring bolt through the centre sufficiently free in the plate to allow the ship to turn in the vertical plane. This steel plate is held in position by eight wires, and backed up by wires leading to the same number of patches stuck on the envelope. The space between the back of the ring and the envelope is fitted with a rubbing pad to prevent the envelope from being injured by chafing.

The two sides of the crutch on the mast are fitted with circular pads which correspond to the curvature of the bows of the ship, and are parallel with the patches described above. Two small hand-operated winches are also fitted opposite to the holes in the circular pads. Before bringing a ship to the mast it is turned so that a line drawn through the pads would be at right angles to the direction of the wind, then the ship is walked as close as possible to the mast by the handling party.

A wire led from another small winch at the foot of the mast through a block in the bottom of the crutch is secured to the mooring point of the ship, and the ship hauled down until two men, one stationed on each bow, are able to secure their winch wires to the ring bolts on the envelope.

By hauling in on these winches, the ring patches are brought hard against the pads on the bows, and the ship is secure. To keep the ship as nearly as possible in equilibrium, chains are made fast to the car and allowed to trail on the ground; thus, when the ship becomes light, extra chain is lifted, and if the reverse happens and she commences to fall, more weight of chain is supported by the ground.

Experiments were carried out at Barrow-in-Furness with an S.S. Maurice Farman type non-rigid of 70,000 cub. ft. which was moored out for eight days successfully. Although the winds experienced during this period were light, the experiment proved the value of this system, and further tests were carried out at Pulham, by which it was proved that a non-rigid could remain moored out in winds of over 40 miles per hour without sustaining damage.

Experiments with Rigids.

Approval was given in 1918 for the construction of a mast. The mast consisted of a steel tower with a revolving top, and was erected at Pulham. The bows of R.24, an old type of airship, were strengthened for this experiment.

The bows of the ship were fitted with a ball supported by steel tubes projecting about six feet, and on the revolving mast head was a socket in which this ball was

held, thus allowing the ship to pivot up and down about the nose, but no fore and aft movement was possible.

Gas, water and electric light mains were led up the mast and into the ship through a hatch in the bows, and access to the keel was arranged in the same way.

R.24 was taken out of the shed and secured to the mast by hand, the first part of the experiment being to ascertain what weather she could stand, and for what length of time the ship could remain moored out continuously. She remained out for 21 days before being brought back to the shed, and after a fortnight's work on small improvements which had been found to be necessary, was taken out again. This time she was able to remain out for 42 days continuously in all weathers, and the highest wind experienced was 45 miles per hour. During this time she behaved very well, riding easily and remaining steady in the direction of the wind.

Two men were on watch in the control car the whole time, and one on the ground to turn on the water to fill the ballast bags if she became light, or gas up if she became heavy.

By means of these gas and water mains it was an easy matter to counteract all changes in buoyancy, however rapid, caused by rain or rise and fall of temperature.

The ship rode best at an angle of 0° to 4° down by the stern, but the trim did not have nearly such a marked effect on the stability as in the case of the three-wire system.

These trials proved that a rigid airship can remain safely moored to a mast in winds up to 45 m.p.h. in spite of rain, sun, and the general deteriorating effect of the weather.

Landing at a Mast.

After these trials had been completed successfully, the ship was again brought back to the shed for minor alterations before carrying out the flying and landing tests. The following method was employed :—

On the ground a wire rope was led from a kite balloon winch through the mast and socket on the revolving top and laid out along the ground to a distance of 350ft. to leeward. The ship's wire was coiled on a drum inside the bows and the end led through the projecting ball and weighted with a 40lb. sandbag.

R.24 was flown to the vicinity of the mast with the ordinary flying crew, and after having been ballasted up about 300lbs. light, the end of the ship's wire was lowered until it could be shackled to the mast wire.

Directly the two wires were secure, the after-engine was run "astern" and the ship hauled down to the mast by the winch until the ball on the nose entered the socket on the mast and was locked in position.

This landing was accomplished in eleven minutes from the time the ship's rope was dropped to the time she was secured to the mast, and a total of seven men were employed on the landing gear. The wind on this occasion was under 10 m.p.h., the trials were successful, and it was decided to carry out further experiments by easing the ship away from and hauling her back to the mast in stronger winds.

A few days later this was done in a wind of 25-28 m.p.h., but as the winch was broken down the wire had to be manned by a party of men, which was a severe handicap, owing to the time lost between the orders and their execution. The ship yawed from side to side and showed a tendency to override the top of the mast, but was secured several times without damage.

Modifications have since been made to the mast and system in general, and it is hoped to carry out exhaustive trials with one of the 33 Class rigids in the near future.

Conclusions Drawn from the Above Experiment.

Mooring Out.

(1) That rigid airships can be moored out in safety in this country.

(2) No technical difficulties exist in re-fuelling, gassing and ballasting at the mast.

Landing to a Mast.

The general equipment and arrangements were rather too crude for completely successful results to be obtained, but it is generally agreed that with the improvements suggested by this experiment, no serious difficulty is anticipated.

Advantages of Mooring Mast System.

Mast Mooring has several advantages, namely :—

(1) The ship can be moored to a mast with very little buoyancy; in fact, the bows can be actually heavy, provided that the stern is light enough to remain in correct trim.

(2) A ship will be able to land at a mast and re-fuel before continuing her journey or patrol, and in strong winds will be able to remain moored until the weather moderates sufficiently to enable her to be taken into the shed, in the event of major repairs being necessary.

(3) The mast forms an excellent support for the gas, fuel and water mains, which otherwise would have to be lifted by the ship.

(4) A very small number of men are required to secure the ship.

Uses of Mooring Masts.

The commercial airship route of the future will have sheds, used as docks, at each terminus, and masts at which the airships can be landed to discharge passengers and cargo. The intermediate stopping places will consist of a mast and small plant for making gas, and carrying out any minor engine repairs which the ship may require before proceeding on her journey.

By this means it is hoped that airships will be rendered as independent of the weather as a sea-going ship, and will keep to scheduled sailings.

The CHAIRMAN proposed a hearty vote of thanks to the Lecturers, and said after the papers they had just listened to it struck a man who had no scientific knowledge of this work that it was only a question of time before the piloting and mooring out of airships would be practically perfect in all sorts of weather. The only question he asked now was did they know enough about the weather, whether the wind at certain heights and in certain quarters of the globe was always constant and in one direction, or was its change of direction known? It seemed to him that the meteorological experts did not at present know definitely whether the wind was regular in certain directions in certain parts of the globe; but he repeated that the mooring out system was definitely assured.

A point that always interested him and seemed to him a most important one was how many docks were necessary for a certain number of ships operating, in addition to mooring masts.

DISCUSSION.

Wing-Commander T. R. Cave-Browne-Cave congratulated the Society upon having two papers on such essentially practical points read before it. The functions of the Society were so broad that sometimes they had to discuss commercial questions, and sometimes they went into abstruse mathematics, physics, or engineering problems, but their primary function was to discuss aeronautics, and these two papers came under that head. The papers had only been read in abstract and the discussion was necessarily restricted, but he advised everybody to read the papers *in extenso*, as they contained much very valuable information that had not even been referred to in the summaries. There were two questions he wanted to raise. One was the question of bow mooring. Flight-Lieutenant Butcher had referred to two systems of mooring for non-rigids, one by a spar in the bow of the ship and the other by a horse shoe at the head of a headed mast to which the ship was secured at two points some distance aft. Trials of both these systems were carried out at Pulham and the horse shoe system was found the more satisfactory, but he did not think that was the conclusion that would finally be come to. One's natural instinct was that a ship should be moored by the bow. The spar method was developed at Kingsnorth as a side issue from the main function of the station—the design and construction of airships. The horse shoe method was developed at Barrow, where more men and more time were available. When competitive trials were carried out at Pulham they were made under the officer who carried out the trials at Barrow. The object of the horse shoe mast was to prevent rolling. The first system tried at Barrow consisted of securing the ship by a strut coming to a point low on the envelope, and considerable difficulty from rolling was experienced. It was to overcome the rolling the horse shoe was adopted. The principle of mooring rigid airships by the bow had been proved completely satisfactory, and he thought that as soon as the details of mooring non-rigid airships by the bow had been worked out completely, that was the method which would be adopted. It was the simpler of the two. Major Scott referred to the deposition of snow on the envelope and he mentioned that it adhered to the bow of the envelope. He (Wing-Commander Cave) had only seen snow deposited on the envelope on three occasions, and in every case it was confined to the tail of the envelope. It started on the part where they imagined the air-flow left the surface of the envelope. He wished to draw attention to the appendix of Major Scott's paper, which he understood was contributed largely by Flight-Lieutenant Rope, on the instability of airships in certain conditions. That was an appendix of considerable value.

There were two general conclusions which were important. One was the great importance of airmanship—if he might coin the word. Both these papers dealt with the practical handling of an airship apart from the construction and the methods of her flight. It had been his good fortune while in the Navy to be able to compare, in a primitive way, our Navy with those of other countries, and his opinion was that the respect in which our Service was most greatly superior to those of other countries was in seamanship—not in material, but in the method of handling the ships. The same thing was clearly seen in looking back over naval history. The same quality was shown by our own air officers in France, and the achievement of taking the R.34 to America and back was a very great achievement in the handling of an airship; how great only those who knew the mechanical difficulties and the unexpected problems that were encountered could appreciate. His own experience during the greater part of the war was with the design and construction of non-rigid airships, but he was impressed later, when it was possible for him to see what had been done in the handling of the airships, with the great increase in the practical utility of the ships, when the practical details of their handling had been properly developed. When one went round

the patrol stations one saw the small airships taken into places in woods and handled in extraordinary ways which at first sight would appear totally impossible. The handling of the airship played a most important part in their actual utility. Another point he wanted to make was the relative importance of improvement in construction and handling. The compulsory generosity of the Germans, both during and subsequent to the war, had resulted in our having the majority of their experience of 20 years in airship construction and two of practically their latest airships. The design of the R.38, being worked out at Cardington, would probably give equal performance. These ships were as regards lift capable of remarkable endurance. The only doubt was their reliability and the experience which was necessary for their practical use. Extensive long distance flying was necessary to determine what were the defects of present ships, what new characteristics or accessories were required, what weight would be justifiably expended in water recovery gear, and whether it was necessary to be able to burn hydrogen. In the construction of airships in the early part of the war great changes had to be made to meet requirements that could not be anticipated in the first design, and after they had some experience he had advocated as strongly as possible that each first ship should do very thorough tests before the construction of subsequent ships of the same class was proceeded with. It was not always possible, and the troubles that resulted were very considerable. Their activities would be restricted in future by reason of economy, but he was certain they were all anxious that the restriction should not fall on the practical use of the airships. The Society could best help in that direction by the preparation and discussion of papers on practical aeronautical subjects such as those they had had at that meeting.

Colonel GOLD said it was particularly interesting to the meteorologist to hear Major Scott appreciate so clearly the importance of meteorological information in connection with airship navigation. They were still near to the time when Major Scott made his great voyage across the Atlantic and they thoroughly appreciated how great that achievement was and could feel sure that it would fill a high place in history and rank with the greatest achievements of the human race in invention and exploration. Major Scott had emphasised the small distance across which one got high winds. If he would cast his mind back about a fortnight he would find that there was a westerly gale blowing at the surface over the whole extent from north of Lerwick, in the Shetlands, down to Brest, in the north of France, a distance of about 700 miles. If an airship had had to make a journey from Copenhagen to Edinburgh it would have drifted further east as it went further south, and instead of being the kind of curve they had seen from Malta to Pulham it would be a curve towards the Black Sea and back to Edinburgh. That was one of the worst kinds of weather that would have to be met if there was to be airship navigation across such latitudes as these. If, however, airship navigation were confined to latitudes south of Paris the same difficulties were unlikely to occur. It was in latitudes above 45° or 50° that these instances of really high winds or gales over extensive distances were likely to occur. In the winter months it was not unusual to get high winds from the Faroes down to the north coast of France. Major Scott mentioned the difficulty of getting the exact height of the airship above the ground, and he gave as a reason for wanting that height, that he wished to ascertain how high the barometer was at ground level with a view to ascertaining from that the direction in which the depression lay. Major Scott could obtain with sufficient accuracy the direction of the centre of the depression without knowing his height above the ground; if he found the wind at the height at which the airship was, that would give him a more accurate idea of the position of the centre of the depression than could be obtained by any means of measuring the barometer at the ground level from the airship. He understood Major Scott to say that inversions of temperature near the ground were more frequent in tropical regions; but in the Antarctic he thought Major Scott would find an inversion near the ground for about six months in the year and that in the tropics

there was no inversion near the ground on practically any day when there was sunshine, which meant on most days. Inversions near the ground in the tropics were confined—as they were largely in this latitude—to night. One occasionally got the temperature increasing as one went upward even in the daytime. A notable case occurred in France in February, 1917. The thermometer went down to three degrees at ground level and up to 18 or 20 degrees at 3,000 feet. One electrical phenomenon mentioned was very difficult for physicists to accept—the occurrence of a thunderstorm in the upper air with no indication of it at all on the wireless instruments on the ground. It was difficult to understand how there could be such a disturbance within the range of an instrument without affecting that instrument, in the absence of any conducting sheath to protect it. That there could be electrical disturbances at the tops of clouds without corresponding discharges on the ground was a well known fact. Flight-Lieutenant Butcher referred to a steady wind of 45 miles an hour with gusts up to 47 m.p.h. One's experience with anemogram records would not lead one to expect in this country a wind so steady as to have only a range of two miles an hour above the steady value. With a wind of 45 miles there would be usually gusts of 60 miles an hour. There were some places near the coast where the range would not be so big. The gusts might not go above 52 or 55 miles an hour, but he knew of no place where a steady wind of 45 miles per hour would rise in gusts to only 47 miles per hour. In connection with the mooring masts, was the landing effected in a high wind? The mast took the place of the landing sheds, and the ship could, presumably, be landed at the mast when the wind was too high for it to be landed in the sheds. Flight-Lieutenant Butcher gave them no information about the strength of the wind *at the time of landing* during these experiments although he said the wind, while the ship was moored to the mast, rose to 40 miles an hour. That was really the fundamental problem to be solved—to get the ship moored safely to the mast at the actual time when high winds were blowing.

Captain Bygrave said until recently his air experience had been confined to aeroplanes. He had the good fortune to take part in the 1,100 mile Handley Page Navigation Flight, to which Major Scott referred, and he then came to fairly definite conclusions as to the accuracy to be expected from bubble sextants and other navigational apparatus in the air. Those conclusions were greatly modified, however, when he took a 10-hour flight in the R.33. The steadiness of an airship came as a revelation and he found that a much higher degree of accuracy could be obtained than he expected. He was informed by the pilot that the day was more bumpy than usual and the conditions were therefore not particularly favourable for observations.

Drift could be taken with great precision, as practically no yaw was present, whilst in an aeroplane 10 to 15 degrees of yaw is often met with, and it is necessary to take the average of several drift observations. When over the sea it was usual to drop a flare in order to take the drift and time the "ground speed" as it floated astern. There would appear to be no special provision for taking this type of drift from the control car of airships, and he suggested that this matter should receive consideration in future designs.

The compass, of the Kelvin America type, was very steady in flight and the oscillations, which often amount to 10° in aeroplanes, were always confined to one or two degrees, and sometimes there was no apparent movement at all for a considerable period.

He took about a hundred observations with the R.A.E. bubble sextant of the sun, moon and stars. The wild oscillations of the bubble met with on aeroplanes, which may amount to as much as two degrees, was quite absent, and observations could be taken almost as easily as on the ground. For fore and aft observations the maximum error was 10 minutes of arc, and for athwartships 15 minutes of arc. By taking the mean of six observations it would be possible to reduce the error

to 5 minutes of arc. This would allow a position line to be drawn within five miles of its correct position, and at night when the stars are visible, the position could be absolutely fixed within eight miles. This is quite accurate for all practical purposes. Under these circumstances it did not appear to be necessary to use cloud horizons, which had proved unreliable as the top of a cloud layer may be of varying height, and in any case, having to alter the height of the airship, in the manner described by Major Scott, is a serious disadvantage. With regard to the use of the reflection of the sun in still water on the ground, this has such limited application that it is hardly worth serious consideration.

With regard to the reduction of sextant observations, the enclosed cabin affords great comfort, and the methods used at sea can easily be used. Owing to the speed of the airship, it is very necessary to reduce the time taken to a minimum, and a slide rule has been designed that allows the position line to be drawn on the map within five minutes of taking the sextant observation.

He thought that, with existing apparatus, there should be no difficulty in obtaining an accuracy comparable with that obtainable at sea in fast craft such as destroyers, and certainly three times the accuracy obtainable in heavier-than-air craft is to be expected.

With regard to future developments, Major Scott has emphasised the need of an instrument for indicating the true height of aircraft above the ground. He did not believe that any practical solution to this problem had yet been found. The reflection of sound, the capacity of the earth, the electrification of the atmosphere, and integrating vertical accelerometers offer interesting theoretical possibilities, but the application of any of these principles to an aircraft instrument is full of difficulty. Until some inventor provides the required instrument, all that can be done is to make the best of the present altimeter. The accuracy of the instrument could be improved by taking the temperature of the air at the height of the aircraft into consideration, and if the changes in the height of the barometer at ground level were communicated to the airship by wireless during a long flight, considerable accuracy could be obtained.

It is interesting to note that there is an alternative method of obtaining the speed and direction of the wind, when the height is not known, which does not demand a change of course such as described by Major Scott. This consists of timing the relative ground speeds at two different air speeds, and would appear to be particularly applicable to airships where such a large range of speed is available.

There is another point of particular interest in connection with airship navigation. During the day time, the measurement of the altitude of the sun gave a position line, and the most probable position of the aircraft on that line has to be determined from its dead reckoning position. If the azimuth of the sun could be taken at the same time as the altitude a definite fix could be obtained. On aeroplanes the magnitude of the accelerations seem to prevent azimuth observations being of sufficient accuracy to be of use, but the steadiness of airships and the absence of yaw would appear to bring such observations within the bounds of possibility. If the azimuth could be measured within one half of a degree, this would fix the position within 20 miles under favourable circumstances. This would be very valuable after flying some time above clouds or out to sea.

Mr. C. I. R. Campbell (Superintendent of Airship Design and Construction) said the lecturers marked a new advance as they dealt with specialist sides of aircraft. That was the direction in which papers should now branch out—the consideration in detail of important parts of the subject. In many papers it had been pointed out that on airship journeys it was very easy to get through or round the weather. The slides shown by Major Scott proved pretty conclusively that that was correct and would satisfy a great many doubters. As regarded the effect of adverse winds upon airship journeys, it was the case that over a short journey

the regularity in the running of an airship was bound to be poor. One essential advantage of an airship was her ability to go very long journeys, and over the greater part of such journeys she had greater choice both of position and direction of flight than an aeroplane, and if she had the meteorological information in good time she could do a great deal to dodge the weather or even to take advantage of it. When nearing, or just leaving, the landing ground she was fairly tied as to position, but even then she was not tied to direction. She could leave her post in any direction which the weather conditions rendered advisable. Under these conditions it would be rarely that an airship could not do her work with reasonable regularity. It was an essential point of an airship, compared with the ships we had been accustomed to, that her speed, while not so very much greater than the winds that were met, was much greater than the speed at which the depressions moved. While, therefore, the ordinary ship could not dodge depressions to any extent, but went plugging through them, an airship need not do so. Referring to Flight-Lieutenant Butcher's paper, he thought the great work of airships was going to be done with large rigids. They had the capacity and the power which the smaller ships had not, and a good mooring system was the only thing that made them possible in that sense. Experience showed that a large airship could not be handled on the ground, at least not as a commercial proceeding, in strong winds. The solution was not to come to ground, but to remain a hundred feet or more above it, and that was the solution offered by the mooring mast. Without that the development of airships could not go on, and too much importance could not be attached to it. They could now see their way through the design and construction difficulties of airships up to sizes considerably bigger than had yet been attempted. He did not mean that they could make the best possible airship of four or five million cubic feet, but they could make a thoroughly good serviceable one of high performance. The point that required attention all the time was mooring gear, and they must hope that the next year would see that in the forefront of development work.

Mr. J. R. Pannell said he would have liked to discuss the early points in Major Scott's paper, but as they had not been read a note would be the most suitable method of adding a few remarks. With regard to superheating, in his limited experience of airship flying he found the ship practically the whole time pitched either nose up or nose down, due to superheating. It seemed an important question. The resistance of the airship was very appreciably increased by the angle at which she flew, and he thought that was a problem which would have an appreciable effect on speed when the solution was found. Major Scott suggested that electric storms were not a source of danger, as German airships had been struck on two occasions and had not been destroyed. In what way was it decided that the airship was struck, was there a spark from some part of the airship? Also two occasions was a very small number, and until a good deal more experience was gained he thought it must be considered that there was considerable danger. Major Scott remarked that he had only known snow to accumulate on the head of an airship; but in Commander Cave's experience it was deposited near the tail. This accumulation of snow gave an interesting insight into the flow round an airship. He remembered an occasion during a night flight of R.32 on which part of the apparatus lowered from the airship consisted of a streamline weight. Owing to the low temperature they were unable to continue the experiment and hauled in the weight; there was an accumulation of icicles on it, but only at the extreme nose. They were two inches or more in length, and there was no ice anywhere else.

With regard to wire mooring, he had hoped his colleague, Mr. Fraser, who had carried out a number of experiments with models of that system, would have been there, but unfortunately he was unable to be present. He hoped he would send a note to the Secretary on the subject. He would like to refer to Flight-Lieutenant Butcher's statement that experiments on the three-wire system had

been carried out in a wind tunnel at the N.P.L. Models were constructed and the displacements of the various parts measured under applied loads. These loads represented the wind forces calculated from experiments on airship models in the wind tunnel, and in that sense they were experiments carried out in the wind tunnel; but the displacements were actually measured on small models fixed to the floor. Flight-Lieutenant Butcher mentioned that difficulty was experienced in keeping R.20 moored steadily in "open-hawse" position. The system used on that occasion was N.P.L. modification number one. The need for greater stiffness under those conditions was confirmed soon after the full scale trials by experiments on models. The parallelogram system was recommended at a later date, as it promised to give considerably increased all-round stiffness. Shortly after a design was completed which was suitable for the later classes of airships. Here the base was 400 feet, and the ground left clear of all obstructions, and the system was, theoretically, more efficient than any of the 800ft. systems. Flight-Lieutenant Butcher thought a large ground area a disadvantage. That objection could scarcely prove serious with a 400ft. base. A hollow swivel at the mooring point would facilitate gassing and the maintenance of trim. With the 400ft. base the stern cleared all cables, and no trouble arose with the after guys.

It was of extreme importance that they should have an accurate record of the performance of all airships. Even with the obsolete ones it was very desirable that experiments should be carried out, and a ship marked for deletion could often be modified in a manner which would not be permissible for a ship on normal service. Nothing would advance the design of airships so much as information of that type.

In extension of his remarks at the reading of Major Scott's paper, he should like to add a few comments upon the early part of the paper which was omitted at the lecture. It appeared that the fundamental points dealt with in this portion of the paper would be more readily appreciated if the subject were treated in rather greater detail.

Under the heading "Aerostatics" the equation $PV = K$ is used to express Boyle's law, P being the pressure and K a constant; a few sentences later the same symbols are employed but they have different meanings.

The complete expression for lift of unit volume of a given sample of hydrogen (L) may be written

$$L = l_0 \times p \times B/B_0 \times T_0/T \quad . \quad . \quad . \quad . \quad (1)$$

where B and B_0 are values of the barometric pressure, T and T_0 values of absolute temperature, l the lift of unit volume of pure hydrogen, and p the percentage purity of the gas; the suffix o denotes normal values of pressure and temperature. The equation in the paper has been abbreviated to

$$L = (B/T) \times P \times K \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where P is the purity, so that the constant K now contains those quantities which are present in (1) and not in (2) (l_0T_0/B_0) in addition to values "depending on the units used."

Similarly in dealing with the effect of superheating on a partially full gas bag, the volume of the gas (V) will be given by

$$V = V_0 \times B_0/B \times T_1/T_0 \quad . \quad . \quad . \quad . \quad (3)$$

where T_1 is the temperature of the gas. This formula is given in the paper as

$$V = (T_1/B) \times K \quad . \quad . \quad . \quad . \quad . \quad (4)$$

and K must now contain $V_0\, B_0/T_0$.

The lift (L_V) of this volume of gas (V) under the new conditions will be given by

$$L_V = L_0 \times V \times B/B_0 \times T_0/T_2 \quad . \quad . \quad . \quad . \quad (5)$$

where T_2 is the temperature of the air, or as given by Major Scott

$$L = (B/T_2) \times K \times V \quad . \quad . \quad . \quad . \quad . \quad . \qquad (6)$$

where K includes $L_0 T_0/B_0$; therefore K in equation (2) is equal to K in equation (6) except that in the former there is the lift of unit volume of pure hydrogen, and in the latter of a certain sample of hydrogen. Substituting for V in (5) we get, for the total lift after superheating

$$L_v = L_0 V_0 \times T_1/T_2 \quad . \quad . \quad . \quad . \quad . \quad . \qquad (7)$$

or in the form used by Major Scott

$$L = (T_1/T_2) K \quad . \quad . \quad . \quad . \quad . \quad . \qquad (8)$$

It will be observed that the increase of lift in a partially filled gas bag is proportional to the degree of superheat, and independent of changes in the barometric pressure. The physical explanation of this is of course that increase in density of the air displaced is compensated by decrease in its volume. The effect of superheating is due to change of volume and there would be no appreciable change in lift due to superheating a bag full of gas. Changes of density of the gas have been neglected throughout.

The value of the section dealing with aerodynamics would be increased for those with limited knowledge of the subject, if the methods of deriving the relation of the various quantities on change of size were given in greater detail.

Commander F. L. M. Boothby did not think anyone could say what should be done when one was caught in a thunderstorm. It would be very useful to pilots to know how to proceed. He knew of a German pilot who was caught in three thunderstorms. He came down and got through all right. Another pilot had been in ships which were actually struck on two occasions, both times while the aerial was down. Did the aerial save her by causing the flash to take place well away from the hull, or would she never have been struck had the aerial been hauled in? The exhaust gases from the motors were good conductors, and in view of that it would be interesting to know whether it was better to stop the motors or run them. If a committee could be got together to go into the best action to take in a thunderstorm something useful might be evolved. He thought Flight-Lieutenant Butcher touched very little on the more important side of the mooring question—the work over water. Unless an airship always landed light, ashore, there must be a landing party to catch the cars, but commercial airships would carry all the load possible and they might have to land heavy. In that case, unless a landing party was used they must come down over water. He thought they would get back to the original scheme evolved by Admiral Bacon for Naval Airship No. 1—that airships should moor over water and alight on it, being handled by tugs, not men. This could be applied to landing grounds near London. A place like Brooklands could easily be flooded, and three feet of water would be enough.

Flight-Lieutenant Pritchard said it was, of course, during long pioneer flights, rather than on a series of short flights round a home base, that new knowledge connected with airship pilotage was most rapidly obtained. To demonstrate the problems which an airship captain had to solve, he proposed to take a concrete illustration from the trans-Atlantic flight of R.34, on which he was sent by the Admiralty as a kind of tame spy to collect and record technical data. He took a number of photographs during the flight, and of these, two were particularly interesting as showing an important part of the work which few realise. (Two photos of Major Scott on the R.34 were then shown, one with a worried and the other with a pleased expression.) It might be called original research at a moment's notice. The problem under consideration was the excessive superheating over the ice floes of Newfoundland. This was the first time that an airship had flown over an ice floe and encountered the extraordinarily marked

inversion temperature effect which, under certain conditions, was experienced. If Major Scott had not solved this new and unexpected problem correctly, R.34 would, on the ensuing night, have become so heavy, due to the dissipation of false lift, that it would have been necessary to burn so much petrol to keep her in the air that she would not have been able to reach her landing ground in America. He hoped Major Scott would forgive him for showing the slides. They were taken without his knowledge and he knew he secretly wished they were destroyed. It was comparatively easy to fly a high performance ship over routes which did not tax her endurance to the uttermost, but it was when piloting a comparatively obsolete ship like R.34, possessing too small a range and too slow a speed to fly the 3,000 odd miles from Scotland to New York in the teeth of a prevailing wind, that true skill in piloting came to the fore.

He would now refer to a few of the technical points paised by Major Scott. During a normal long distance flight, superheating reduced the paper performance of a present day rigid by as much as 10 per cent., due to the large changes in buoyancy which necessitated flying the ship nose down for the majority of the day and nose up during most of the night. Under normal weather conditions it took about three hours to obtain maximum superheating during the day. If this lag could be materially increased, most favourable results would be obtained. This could be effected in two ways—by increasing the size of the ship, which means that the ratio superficial area/volume decreased, and by improving the outer cover so that less heat passed through a given area in unit time. If this superheating lag could be increased to about nine hours instead of the present three hours, the maximum superheating would be greatly decreased and a much more equable temperature would be maintained. In this way the practical performance would more nearly approach the paper performance. The mooring problems were of extreme importance and could not be too strongly emphasised. At present the performance of an airship was far in advance of the ground organisation. Although it was most important from the hull designer's point of view to know that hull design advanced more than anything else it was not a sound proposition. Ground organisation and research should be pushed ahead to catch up to the hull designer.

Major SCOTT, replying to the discussion, said the case he had taken in regard to the question of snow was the R.9. The deposit was on the forward end of the parallel portion. It depended very much on the shape of the ship. With a good streamlined shape it may deposit on the tail. It was the wet snow that stuck, and the correct thing to do was to get into the dry snow. He agreed with Colonel Gold that in the case of a gale, such as he described, it would be difficult to fly in the Atlantic or anywhere on the northern side of Europe. Most of the cases he (Major Scott) had considered were over the Mediterranean and nearer the tropics, which, after all, was a trade route. Even in that case, with good warning, an airship coming from the Mediterranean could have got through it all right. The height of the barometer on the ground was really not so much to give the pilot the direction in which the centre of the depression was as to enable one to know how long it would take him to get there. He wanted to cut across the centre of it as quickly as possible. The idea was to be able to judge whether one was going in the right direction to strike the centre of the depression. The Italian pilots had experienced, in the Mediterranean, a great deal of the inversion of temperature. They almost invariably get it during certain parts of the day. He agreed with Captain Bygrave that some method of taking the tail drift was necessary. Something to enable this to be done should be put right in the tail of the ship. He thought it had been considered. He agreed that ground organisation required particular attention at the moment. In the German airships which were caught in thunderstorms the wireless weights were burnt off. The bow was struck in one case and the bow girders were fused together. He thought the motors should be kept running in a thunderstorm, because of the

disturbed state of the air, regardless of whether it was the best thing or not from an electrical point of view. Alteration in height was the only thing he knew of to get out of a storm.

Flight-Lieutenant BUTCHER, also replying to the discussion, said the question of the velocity of the wind at the time of mooring was dealt with in the full text of the paper. The ship landed the first time in a wind of between 7 and 10 miles an hour, and as the ship was of an old type the mid-ship car was taken off, reducing her speed to 25 miles an hour to give more disposable lift. As they could not conduct landing experiments in winds of over 20 miles an hour, it was decided to carry out tests by easing her out on the mooring wire and hauling her back to the coupling. This was accomplished in winds of 28 miles an hour without damage. He had not much experience of mooring over the sea, but it had great possibilities, and he thought it would be worth somebody's while to bring out a paper on it.

A vote of thanks to the Chairman was proposed by Mr. A. E. BERRIMAN, who said the warmth of their reception of the former would be increased on account of the subject for which he had just expressed his interest.

NOTE ON THE MOORING OF AIRSHIPS BY "FREE" WIRE SYSTEMS.

BY R. A. FRAZER, B.A., B.SC., and L. F. G. SIMMONS, B.A., A.R.C.SC.

In his recent lecture on "Airship Mooring and Handling," Captain Butcher refers to certain experiments carried out with the use of models in connection with three-wire mooring. It is, perhaps, useful to add some further details of these special experiments, which were conducted at the National Physical Laboratory.

Mention was made by Captain Butcher of the original or "fixed" three-wire system (see Fig. 1), which originated from the emergency mooring of R.9. Its defects lie in the occasional slackening and subsequent impulsive tightening of one or more of the mooring cables when the airship is riding in gusty weather. In the particular modifications introduced by the N.P.L., breakdown due to this contingency is eliminated.

The Mooring of Airships by Free Cable Systems.

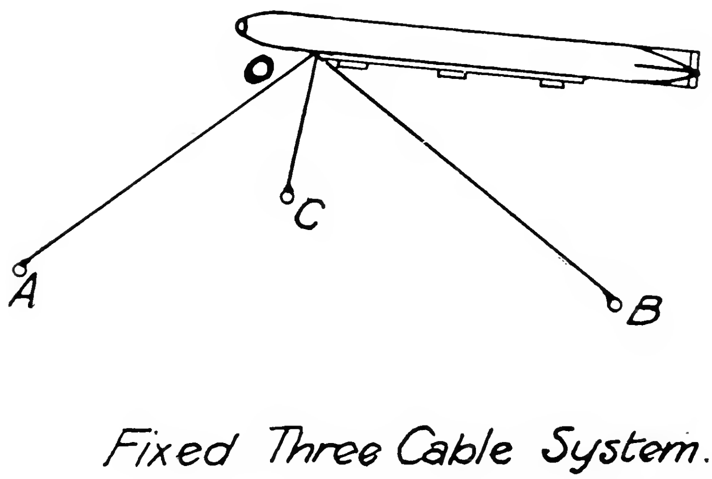


FIG. 1.

A B C denote fixed bollards.

Certain characteristic features of the "free" systems serve to differentiate them from other systems of mooring. In particular, they permit of the airship swivel moving over a geometrically defined surface and displacing to new positions as the wind varies in speed or direction, without loss of tension in any of the mooring members and without undue loss of altitude. In order to secure this type of constraint, the swivel is attached to a non-redundant arrangement of mooring cables, in which the cables pass over suitably disposed blocks or connect to fixed bollards or moving splicing rings. The distance through which the swivel will displace under given alterations in the wind varies with the design of the mooring system, and the system possesses a greater or less degree of "stiffness" according as these swivel displacements are small or marked. Thus, in their general conception, these "free" systems are not necessarily confined to the use of three main mooring cables arranged equilaterally.

In order to lay out designs suitable for prescribed classes of airship, progressive experiments were carried out with scale models of a number of systems. It was found convenient to represent the cables by lengths of fine silk fishing cord, and to reproduce the blocks as small light metal pulleys mounted on point bearings. Information from wind-channel experiments was utilised indirectly by

applying at the swivel loads equivalent to the predicted forces on the airship due to typical conditions of trim and representative wind speeds and wind directions. Suitable allowance was also made for static reserve lift. By measurements of the displacements undergone by the swivel under such loads, sets of "displacement-loci" were determined, each curve of which exhibited the positions of the swivels appropriate to steady winds of given speed blowing from different quarters. These displacement curves were found to be in general not plane contours. A direct comparison of the "stiffness" between two systems was possible by comparing the relative sizes of corresponding displacement-loci in the two systems. In addition, the effects of lateral gusts on two systems were compared by analogous methods.

An illustration of a typical "free" cable system, comprising four mooring cables, is given in Fig. 2. This system was investigated in connection with mooring of 23 class airships.

The Mooring of Airships by Free Cable Systems.

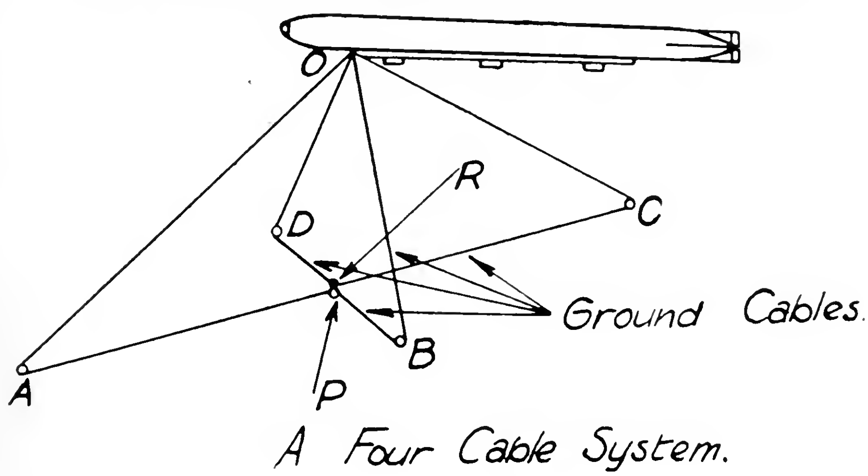


FIG. 2.

A B C D denote swivelling pulleys attached to fixed bollards.
P denotes a pulley fixed to a splicing ring.
R denotes a splicing ring.

In the above the base points A B C D are arranged at the corners of a square. Two of the mooring cables are continuous through two of the fixed pulleys, A B, and the moving block P; the remaining two mooring cables pass over fixed pulleys C D, and are spliced at the ring R. It will be seen that by use of a cable linkage of this type the swivel O admits of continuous displacement over a wide range, during which every cable is maintained in tension.

In Fig. 3 a characteristic displacement is given, representing the locus of projected positions assumed by the swivel in this system when the airship is moored out under zero reserve lift in steady winds of 60 miles per hour at an upward angle of inclination 6°.

For three selected points of this locus (indicated by small numbered circles) the corresponding wind directions are shown by the aid of arrows. Points similarly numbered, lying off this locus, determine the further lateral displacements of the swivel when the airship is struck by a representative gust of force two tons on either bow. Reference to Fig. 3 illustrates that the amplitude of the displacements due to gusts of given magnitude may vary with the quarter from which the wind is blowing.

It is of importance to observe that when the reserve lift of an airship is assumed to be zero (case of static equilibrium), a displacement curve is dependent only upon the angle of trim and not upon the wind speed. In general, at each

point of a displacement locus the resultant force on the swivel coincides in direction with the normal to the "swivel-surface" which contains all possible positions of the swivel. A particular locus is, in fact, defined not by *magnitude* of the resultant force but by its *direction*; when static lift is absent and the trim angle constant the force direction—and consequently the locus—is independent of wind speed.

The Mooring of Airships by Free Cable Systems.

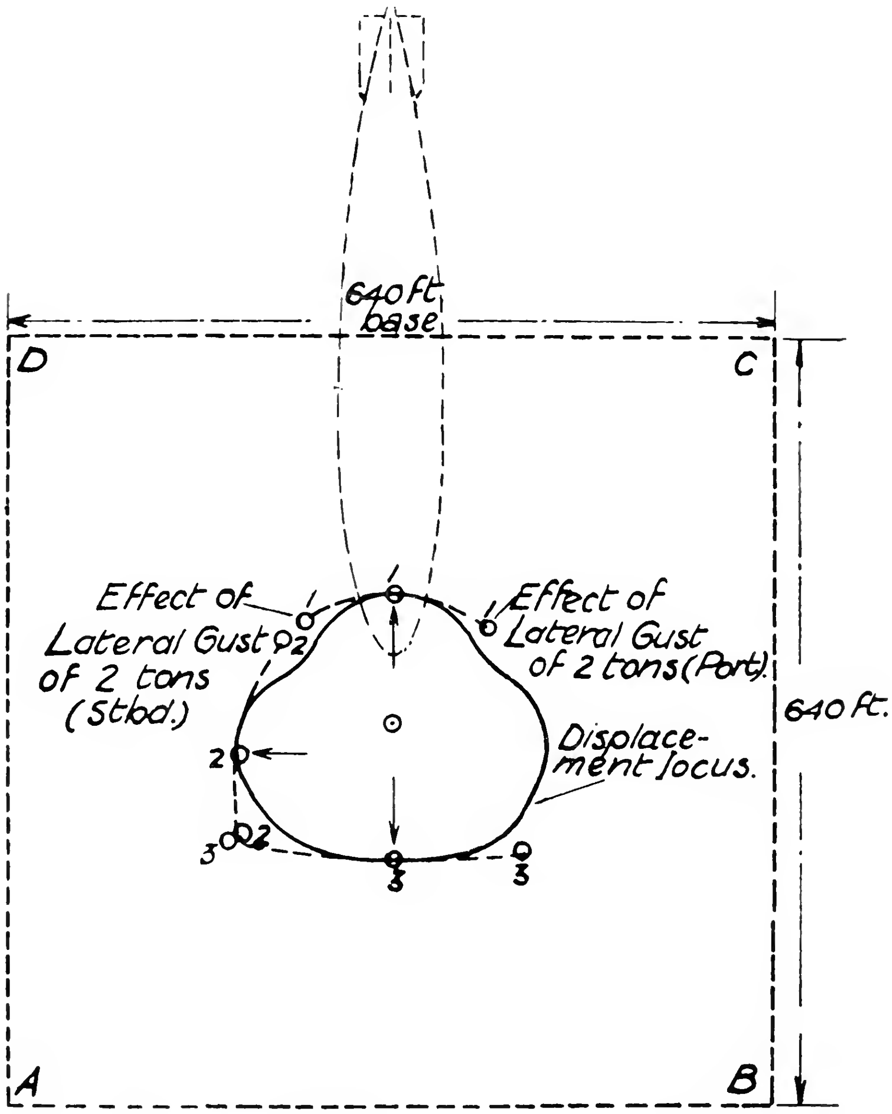


FIG. 3.

Projected displacements of 23 Class airships when moored out on four cables in steady and gusty winds of 60 m.p.h.

Angle of trim, 6° nose up. Reserve lift, zero.

From this viewpoint it is preferable to regard a set of displacement curves as defining loci along which the normal directions to the "swivel-surface" are prescribed. Once a set of these curves are available, it is at once possible to predict the position of the airship for given circumstances of mooring by calculating the direction of the resultant of the static and aerodynamic forces acting on the airship.

Reference was made by Captain Butcher to a number of representative types in which three main mooring cables are employed and an 800ft. equilateral ground base.

System Mark I.

The first type, designated as Mark I. (see Fig. 4), was developed originally in connection with full-scale mooring experiments on R.26; it was also employed for R.34 at Mineola.

The Mooring of Airships by Free Cable Systems.

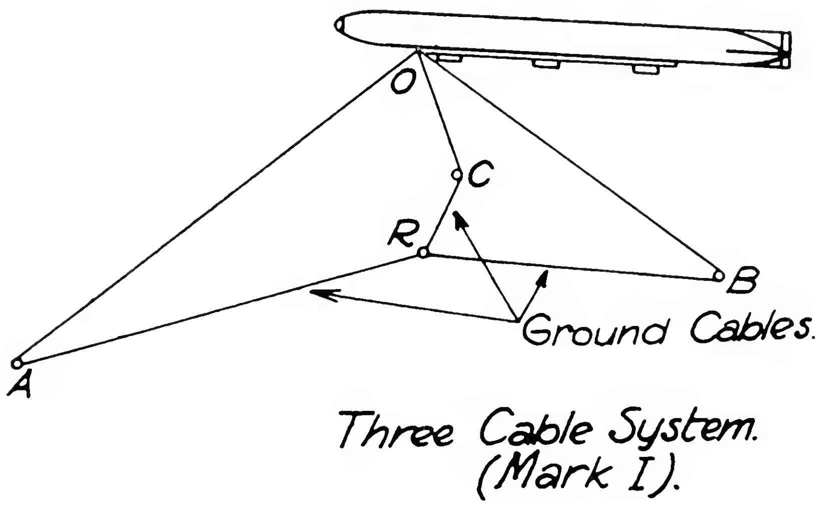


FIG. 4.

A B C denote swivelling pulleys attached to fixed bollards.
R denotes a splicing ring.

Displacement curves due to steady and gusty winds were derived for this system; these naturally showed a symmetry about the three median planes passing through the vortices of the ground base. From the experiments on the model it was concluded that better lateral stability was to be expected when the airship was riding across a base line than when it was riding over one of the vortices A B C. This conclusion was in agreement with observations on R.26 during the full-scale experiments.

System Mark IV.

An all-round improved " stiffness " was to be expected from subsequent measurements of a model system in which the central ground ring of the previous anchorage was replaced by a parallelogram cable linkage. A perspective drawing of this system (Mark IV.) is given in Fig. 5. Each of the three mooring cables is here attached to a corner of the parallellogram, whilst a short strop length connects a fixed bollard (D) to the fourth corner.

It was found that the " stiffness " could be varied to conform with particular requirements by judicious adjustment of the lengths of the main cables, the length of the strop and the dimensions of the parallelogram.

System Mark V.

A system (see Fig. 6) more particularly suited to the demands of airships of the 33 class is described below. It offers a number of important improvements, in that it is both more compact in dimensions than the earlier systems and presents a steeper pyramidal grouping of the mooring cables in the locality of the swivel. The advantage in this latter feature lies in the elimination of any possibility of these cables fouling the forward car when the airship acquires a severe upward angle of pitch. It also appears from the experiments on models of this system

that a considerably higher degree of stiffness can be secured than with the previous types of anchorage.

The system (Mark V.) may be specified broadly as comprising a short pyramid of three equal "ship cables," Oa, Ob, Oc, whose lower extremities are attached to a "continuous" length of cable running through ground pulleys A B C at the apices of a 400ft. equilateral ground base. A symmetry exists in the grouping of the cables in the "no wind" position with regard to a vertical axis through the swivel, the plan of the continuous cable in this position resembling a three-point star. Thus for all positions of the airship the cables are freely sup-

The Mooring of Airships by Free Cable Systems.

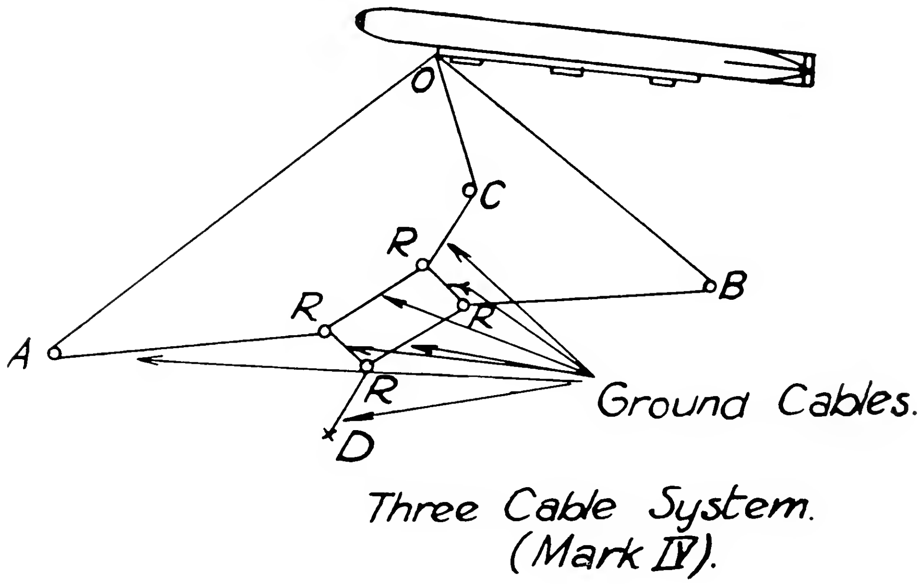


Fig. 5.

R denotes splicing rings.
D denotes a bollard fixed along the external bisector of A B.

ported above the ground—or above the level of the water in the case where the airship is moored over water—leaving the handling space clear of obstruction. The elimination of damping forces, introduced in earlier systems by frictional forces between certain cables and the ground, is not regarded as serious, since such forces are estimated to be small in comparison with the wind forces operating. On the other hand, a distinct advantage results from keeping the system wholly clear of the ground, since the cables are saved from any deterioration which the ground friction might entail. Should it be found expedient in practice to introduce further friction, auxiliary braking methods could be devised.

Certain practical facilities are, it is thought, likely to accrue, without impairing the efficiency, from the use of short strops attached to the bollards A B C, for carrying the ground pulleys. It has been suggested by the Airship Department that the "ship cables" forming the upper pyramid could conveniently be carried by the airship during flight and lowered into position for purposes of making fast. Under such circumstances a small adjustment provided by the strops would materially assist during the operations entailed in attaching the ship cables to the splicing rings in the continuous cable.

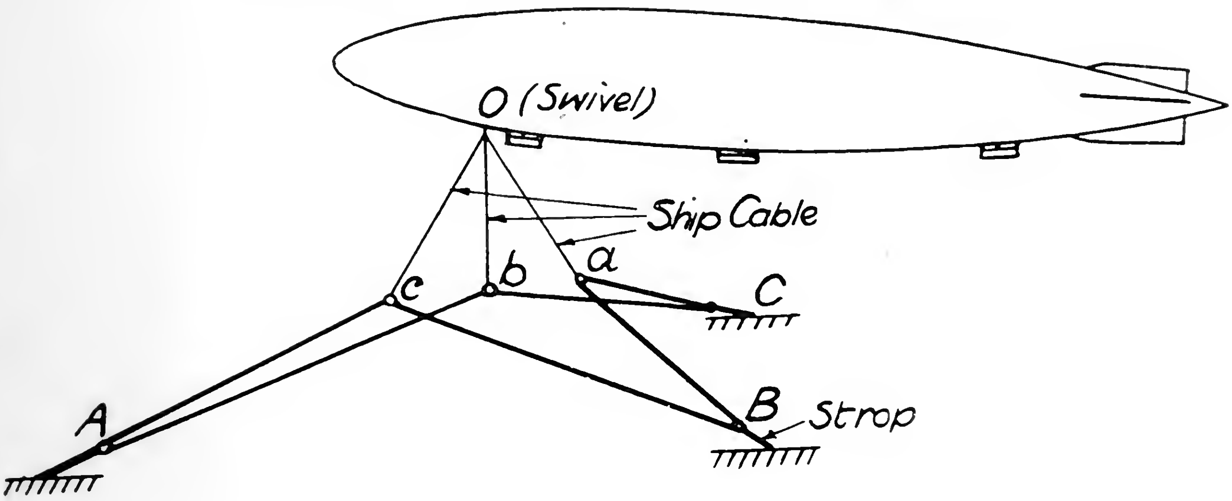
With choice of cables of certain standard lengths the system may be made markedly stiffer than the earlier systems as regards both down-wind displacements and transverse displacements due to gusts. Any increase in these lengths lends additional freedom to the system; whilst reduction of length introduces further stiffness.

Loss of altitude resulting from displacement of the swivel is confined within

reasonable limits; with the airship in equilibrium and normal trim this loss amounts to less than 5 per cent. of the initial altitude of the swivel in the "no wind" position. The initial altitude is, however, readily susceptible to small changes in the lengths of the strops, a 10ft. strop producing a 17 per cent. increase of altitude in the "no wind" position.

In order to specify the cable sizes for any system, information was required relating to the maximum tensions likely to arise in practice. Determinations were consequently made of the cable tensions corresponding with the worst conditions. These special investigations were expedited, in the case of the Mark V. system,

The Mooring of Airships by Free Cable Systems.



System Mark V

Fig. 6.

A B C denote swivelling pulleys attached to fixed bollards.
a b c denote splicing rings.

by the use of a small tensionmeter, designed to record accurately tensions of the order 2-3lbs.; and this also enabled a more detailed exploration to be undertaken of the tensions in the separate cables.

Captain Butcher referred to certain difficulties which were experienced during the trials of System Mark I. in connection with the fouling between mooring cables and the handling guys and other auxiliary ropes carrying compensating ballast at the stern. With use of the 400ft. base, to which System Mark II. is designed, no such trouble need arise.

In conclusion, it should, however, be emphasised that with such mooring systems, as with others, efficient and convenient ballasting arrangements are essential for satisfactory maintenance of trim. A hollow type of swivel would materially assist in such gassing and ballasting operations.

DEVELOPMENT OF GIANT AIRCRAFT IN GERMANY.

I.

Introduction.

In attempting to survey the growth and progress of the "Giant" aeroplane in Germany, it is first of all necessary to review the circumstances and conditions which determined and necessitated the direction of effort in this direction, and secondly, to indicate roughly the accessory circumstances peculiar to the conditions of the Central Empires during the war at the period when giant aircraft first began to appear, and to distinguish if possible the influence of these circumstances where they bear on development in a manner either conflicting or diverse from the conditions appertaining in Entente countries.

Such a preliminary survey is absolutely necessary in order to disabuse the mind of its natural tendency to compare the completed individual German giant aeroplane with its corresponding Entente type; and at the same time to prepare one of the various confusing and unexplained peculiarities which must tend to mislead, if the ruling circumstances are not first made clear.

In order to eliminate from our survey all unessential circumstances which might tend to confuse the main issue, we propose to treat the subject as a comprehensive whole, avoiding wherever possible reference to the minor peculiarities in constitution, design, or performance, of any one individual machine. So delicate a compromise is the modern aeroplane that any other method of examination must necessarily be misleading, and indeed in this way only is it possible to sift from the mass of information available those essential and fundamental facts which it is our object to discover and without a clear impression of which it is impossible to formulate a conclusion, or turn to profit the accumulation of experience represented by the various examples of German giant aircraft.

Reasons for the War Development of Giant Aircraft in Germany.

The progress of any new development is primarily due to competition. In a state of war the normal conditions of competition become accentuated in the struggle for supremacy in every branch of war activity.

In the early stages of the war, both the Entente and the Central Empires were in parallel circumstances as regards their resources in aeroplanes and seaplanes. Only single-engined machines were at this time available for war purposes, and in some respects the aeroplane considered as a "glider" was in advance of its engine.

The first effects of intensive war competition was naturally to be expected in the shape of improvements in the petrol motor.

Under war stimulus the improvement of the aeroplane motor was rapid, and is to be traced in the continually increasing horse-power of aeroplane engines. Due to this initial development the aeroplane, followed by the seaplane, rapidly became factors of importance in the world war. The influence of the aeroplane motor on aeroplane development will be again referred to later. It is important, however, at this stage to note that engine improvements were at this time of vital importance. Up till 1915 when the military situation began to become stabilised, the ordinary one and two-seater aeroplane and seaplane were sufficient to meet immediate requirements in so far as the state of aircraft development permitted.

Bombing was not at this time seriously considered on the army fronts, but the early successes of the Zeppelins had opened the eyes of the Central Empires to the possibility of aerial attack on rival capitals. The possession of Belgium as a suitable "taking off" ground for attacks on London and other towns made the prospect still more alluring. Germany immediately commenced to experiment with and to construct large bombing aeroplanes. They had at this time no particular incentive in so far as the enlargement of seaplanes was concerned, in view of the fact that the naval Zeppelins were far in advance of her heavier-than-air craft. The development of the German "giant" seaplane was, in consequence, of a much later date than in the case of the aeroplane. Here we notice the first disparity in the aeronautical situation as between the Entente and Germany. The development of Allied aeroplanes and seaplanes took place concurrently, with the seaplane, in so far as size is concerned, ahead of the aeroplane. In Germany the circumstances were reversed, and the seaplane has followed the lead of the aeroplane. In consequence the large or "giant" German seaplanes may be expected to bear a very close relationship to the German "giant" aeroplanes.

The political and strategical importance of aerial bombing having been early made clear to the Central Powers, it was only natural that Germany should at once commence to provide herself with "heavy bombing machines" possessing a long "flight range," and that such "bombing machines" should, under the stress of competition, rapidly become "giant" machines. The Allies had no such definite incentive, and could therefore not be expected to expend the same energy in this direction.

Germany for these reasons was, and still is, considerably in advance of Entente countries as regards experiment and research in the sphere of giant aircraft.

Since the construction of giant aircraft in Germany was directed principally to the purpose of long distance bombing, for which purpose the geographical situation was well suited, we may expect to see further divergences from Entente practices, in that, while the German product was designed almost exclusively for one particular purpose, the Entente bombing and "giant" machines on the other hand were multi-functioned. In a word, the German giant aeroplanes were primarily of strategic value, the Entente aeroplanes of tactical value. This again must be expected to produce a certain difference in type, which will most probably be shown in the minor details such as "handiness" and "maintenance" no less than in the size or overall dimensions. These circumstances are slightly different in regard to the seaplane, where German development in any case commenced at a later date; but the same influence may be expected to make itself felt in that the German giant seaplane is naturally founded on the experience gained with previously constructed land aeroplanes. This last circumstance is of some importance and to it must be attributed the fact that German giant aircraft constructors are in the majority of cases the designers of both seaplanes and aeroplanes. Apart from details we may expect then to find the design and conception of giant seaplanes and aeroplanes very much the same.

The effect of the blockade must also be expected to exert its influence on aircraft construction, and more particularly in the case of giant machines whose dimensions called for unusual "lengths" of wood for the manufacture of wing spars, etc. In short, the shortage of materials undoubtedly influenced the construction of German aeroplanes very considerably, and this constitutes yet another factor which must be reckoned with in comparing the rival machines of both sides.

Moreover, it will serve in several places to explain the reason for various departures in design and construction from what under ordinary circumstances would be the standard and simpler method. The immediate effect of a shortage of raw materials must be expected to exercise an adverse effect on construction;

but it is by no means certain that in the long run the ultimate effects of shortage may not have its compensations in that such a state of affairs is in itself an incentive to invention. In any case, here we may again expect a sharp divergence from the general practice in Entente countries where shortage of materials was undoubtedly felt, but never very acutely, or to anything like the same extent as in Germany.

All these factors then must be borne in mind while assessing the merits and demerits of the machines under review; and it will be necessary to exercise a good deal of care in passing judgment on individual peculiarities in design, lest the cause be forgotten in considering only the effect, and a wrong estimate of value be arrived at.

There is one other minor consideration and yet one of some importance as exercising an influence on all machines and types. A general reference has already been made to aeroplane engine development, and it will now b- necessary to examine this a little more carefully before embarking on the general survey of actual machines.

With the development of the rotary engines we are not here concerned, since their extravagant consumption of fuel renders them unsuitable for long range giant aircraft. The development of giant aircraft was, however, necessarily dependent on the available engine power. The need for increased engine power so far as Entente countries were concerned resulted in the early adoption of the V-type twelve-cylinder stationary motor. Germany, on the contrary, chiefly it appears owing to the conservative attitude of the powerful Daimler-Mercedes combination, who considered that the standard single line, six-cylinder stationary motor could be made to give all the power required, did not commence to develop the V-type engine until considerably later. Too late in fact to allow of such motors taking an active part in the war.

The result of this circumstance is twofold. In the first place, the most powerful German engine units were not as powerful as those of the Allies. Consequently the necessity for providing more and more power for giant machines drove the German designers into adopting designs suitable for a number of motors at an earlier date than was necessary in Allied countries. There is no doubt that this constituted a grave disadvantage; on the other hand, however, the German six-cylinder motors were considerably more economical in relative fuel consumption than their more powerful V-type rivals. The importance of fuel economy in relation to long range giant machines needs no emphasis, but nevertheless this combination of circumstances is of vital importance and must be given full consideration when comparing the German types with the corresponding Allied machines.

In view of the far-reaching influence of these circumstances, it would seem best to avoid as far as possible in our general survey any reference to the individual peculiarities of single machines, avoiding thereby the possibility of giving too much consideration to the special features of any one example, which may rivet attention by reason of its novelty in comparison to Entente experience, but whose very originality may be due to the accident of circumstance rather than to deliberate intention. For this reason it will be best to avoid as far as possible any attempt at comparison as between Allied and German productions, and to confine ourselves to an impartial examination of all the available facts, with a view to extracting therefrom such information as may be of service to the Allied cause.

It is proposed, therefore, to divide the remainder of this review into three portions. In the first part we shall survey the general lines along which development has proceeded, with a view to classifying in distinct "types" the various machines under consideration, and at the same time endeavour to locate that line of advance along which further progress can best take place. In the second portion, under the heading of "Minor features in German Giant Aircraft," we

shall, assisted by the previous investigation in "types" and forewarned by the various circumstances discussed in the introduction, make an examination of the collective minor features of the machines under review, avoiding as far as possible any discussion on the constructional details of any one machine.

In the last part of the survey we shall endeavour to draw some definite conclusion, not as to which is the "best" machine, but as to which type of design as dictated by sound fundamental principles is best suited for progressive development; afterwards pointing, if possible, from the results of German experience, to the means whereby such development can be achieved in practice, and finally turning these conclusions to our own advantage by indicating in outline the "short cut" to military and commercial supremacy in giant aircraft.

II.

DEFINITE LINES OF DEVELOPMENT AND PRINCIPLES INVOLVED.

It is possible to distinguish three important and distinct lines of advance towards the development of German giant aircraft, whether aeroplanes or seaplanes.

(1) "Type A."—Enlargement of aircraft by the increase of power brought about by multiplication in the number of motors; which motors are arranged as conveniently as possible in the wings (*i.e.*, not massed on the centre line, in the fuselage or body).

Examples.—A.E.G., Gotha, Albatross, Staakener (aeroplanes and seaplanes), Friederichschafen (A. and S.) Dornier.

(2) "Type B."—Enlargement of aircraft by the increase of power brought about by multiplication in the number of motors; which motors are arranged in the central fuselage or body and designed to drive one or more propellers through the medium of shafts or gearing.

Examples.—D.F.W., Siemens-Schuckert-Linke-Hoffman.

(3) "Type C."—Radical departure from precedence in design, aiming at a greater all-round efficiency, irrespective of the arrangement of motors or power installation.

Examples.—Junker, Fokker (Limousine) Siemen-Schukert (new type).

It should be noted—and so far as German aircraft are concerned observed with emphasis—that the enlargement of aircraft has been undertaken with the very definite objective of increasing the useful load, and hence the military and civil value of individual aircraft; and for no other reason.

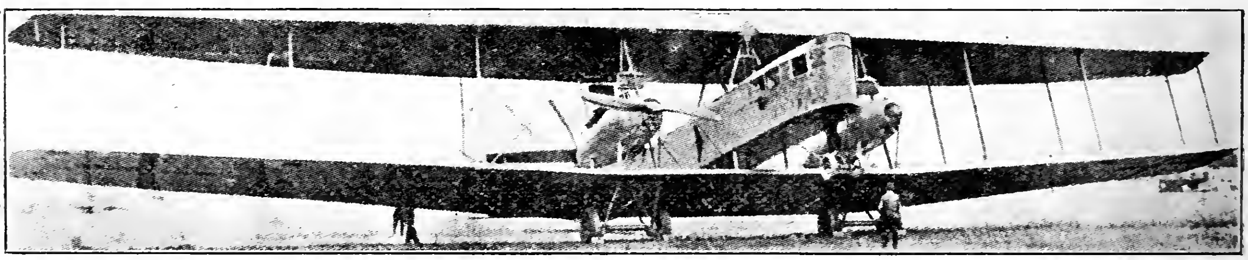
Advantages and Disadvantages of Type A.

Giant aircraft in which two or more motors are arranged in the wings, or at least away from the centre line, make up the bulk of large aircraft in Germany, as in the Entente countries. They have the advantage that the designer undertakes no special experimental work, is assisted by an accumulation of previous experience in the same type, and faces no constructional difficulties. Standard engines and simple fittings without any special or complicated devices are employed, for which reasons construction is comparatively simple and cheap. This form of construction, *i.e.*, with the motors disposed in the wings, simplifies rather than complicates design, and allows of a certain small reduction in the proportionate weight of the wing structure. For the same reason it permits of the span

being slightly further increased without a disproportionate growth in wing structure weight. The arrangement of the motors in the wings facilitates the design of the landing carriage or floats—a point of ever-growing importance with increasing size. For these reasons, and indeed naturally, the development of large aircraft on these lines has been more marked than on any other basis. Unfortunately, however, machines of this class possess all the vices of their virtues. They are, generally speaking, clumsy, and owing to the fact that they adhere too closely to precedent, almost invariably present an immense area of passive head resistance. This point needs no special emphasis, since Entente machines of this type, like the German representatives, are notorious and conspicuous for a multiplication of struts, stays, king-posts, and other "parasite" resistances. This is so much the case that in many instances designers of this type of aircraft base their main claims for merit, not on the increase of useful load obtained, but on the "reliability" of the machine in flight. In the case of two-engined machines there is no longer any doubt that claims for greater "reliability" are devoid of any real foundation, and indeed this must necessarily be the case in any heavier-than-air craft carrying a normal load, where the number of motors does not exceed three. (By "reliability" is meant greater immunity from a forced descent, due to the failure of a motor.)

FIG. 1.

A Type "A" machine (German).
"Staaken" or Zeppelin Giant.



Note the exposed engine nacelles, the innumerable struts, stays, etc., all forming "passive resistance."

Beyond the slight constructional advantages already mentioned, and the possibility of obtaining a good "view" for the pilot and observer with more or less unobstructed accommodation for passengers, bombs and cargo in the central fuselage, the further development of this class or type of machine offers very little prospect of real success. Indeed, the larger existing machines—at any rate of German origin—are already beginning to demonstrate such obvious defects and inefficiency as to render continuance on the same lines altogether unprofitable.

The decline of effort in the direction of progress with this type of design is apparent in Germany as in other countries, and can be seen by the falling off in the number of firms undertaking the design of this description of large aircraft. It has, in fact, become generally recognsed that efficiency cannot be obtained on these lines, without radical departure from the design of existing Type "A" machines.

In a word, the slight advantage in structure weight which is perhaps the feature of this type is more than counterbalanced by the additional "passive" and "parasite" head resistance which characterises such machines. Moreover, the hopes of some designers—who use the same type of design with four motors, placed back to back in pairs—have not in practice been realised, the result being responsible for a still further slight loss of efficiency, which is not sufficiently accounted for by a slight balance in favour of greater "reliability."

Nevertheless, this type of machine, owing to its simplicity of design and construction, has, considered from a purely military point of view, many desirable features, not the least of which is its suitability for rapid production.

Advantages and Disadvantages of Type " B."

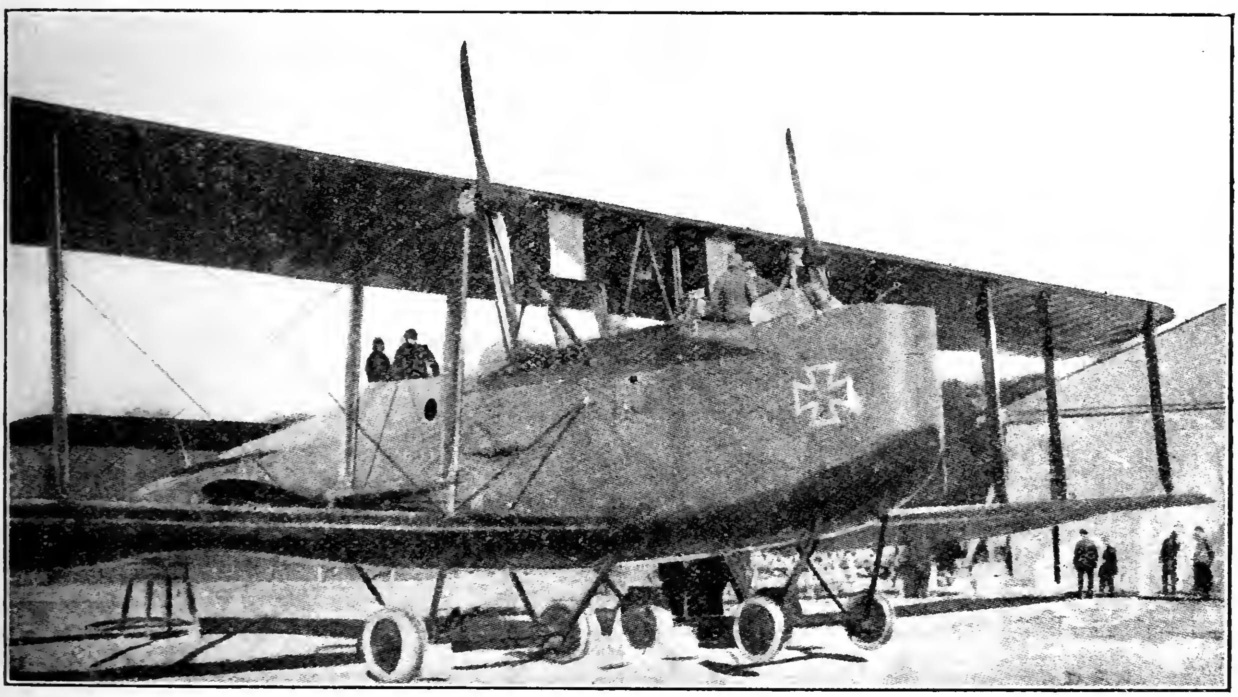
Giant aircraft in which two or more motors are grouped in the central fuselage, driving one or more propellers through gearing or shafts.

The development of this type is undoubtedly largely due to the realisation of the inherent defects in Type " A " aircraft (*i.e.*, the disproportionate increase in passive head resistance), and to a certain extent to the demands of civil aviation for greater reliability. It is for this latter reason, perhaps, that machines of this class have only comparatively recently come into existence.

The outstanding advantages of the type then are:—Firstly, a certain reduction of unnecessary head resistance; and secondly, a gain in " reliability," which may be perhaps still further enhanced by the fact that motors so disposed (*i.e.*, enclosed in the main fuselage) are readily accessible in flight. This latter consideration, whatever its actual merits, is one carrying considerable weight in so far as commercial undertakings are concerned; and this in spite of the fact that the placing of the motors in the fuselage must necessarily to some extent prejudice both the comfort of passengers and the space available for cargo.

FIG. 2.

An example of a German Type " B " machine.



Note the absence of exposed engine units, and the generally " clean " appearance of the machine, denoting a reduced head resistance as compared with Type " A " designs.

There is moreover—although at first sight this appears improbable—an actual gain, due to the employment of gears or gear drives, in that the propeller revolutions can be arranged for maximum efficiency.

(The Germans were apparently early aware of the advantages of gearing, despite the extra weight involved, and even in twin-engined " bombers " of now obsolete type had in some cases fitted gearing between engines and propeller at

a sacrifice in weight of about 16lbs. per h.p., but with a gain in efficiency and "performance.")

The advantages of the type then may be briefly summed up as follows:—

(1) "Reliability" enhanced by the accessibility of the motors.

(2) Reduction in "head resistance."

These two items are to a large extent counterbalanced by the overcrowding of the fuselage with motors, etc., and the constructional disadvantage of having all the weight massed in the centre of the machine. This latter evil, however, is to some extent mitigated by the generally better conditions for adequate lateral control due to a reduced transverse moment of inertia. The massing of the weights in the centre line must however impose a smaller limit on the possible span breadth than in the case of Type "A" machines, and is therefore a serious and fundamental disadvantage in so far as *maximum* size is concerned.

At present, however, the "performance" in relation to the speed of machines of this type shows considerable promise by comparison with Type "A," and if the gears and propeller transmission arrangements should prove "commercially" satisfactory, a certain degree of temporary success and popularity is to be anticipated.

It is doubtful, however, if the type as represented by existing examples can be regarded as a satisfactory basis for important development.

In so far as the arrangements for the gearing of the multiple motors is concerned, there is a large variation within the type, the number of propellers varying from one to four, with a disposition either central as with one propeller, or in the case of four, arranged in the wings. In the former case the disadvantages from a purely military point of view are obvious, as it is almost impossible to obtain a good or even moderately good "view" from the necessarily large fuselage.

Advantages and Disadvantages of Type "C."

Machines designed on lines constituting a radical departure from precedence in design.

Successful machines falling under this heading are at present very limited in number and for the purpose of this review may be taken as being represented by the "Junker," Fokker (Limousine) and Siemans-Schuckert (new type) designs only, of which the Junker is the parent conception.

The "Junker" design would appear to be the only German machine which is based on fundamentally sound and scientific principles. The realisation of the design presents many unusual features, which although generally known are as a rule assessed as eccentricities rather than appreciated at their true significance.

Briefly, the "Junker" firm have aimed at the suppression of all "passive head resistance," and with this as a key to the general design have to outward appearances achieved a brilliant success, the result of which may perhaps be expected to lead to hitherto unhoped for success in the development of giant aircraft. This machine is moreover entirely constructed of metal, and represents the only existing machine which can justifiably be called of "all-metal" construction.

It is therefore proposed to examine more minutely the general basic features of this design.

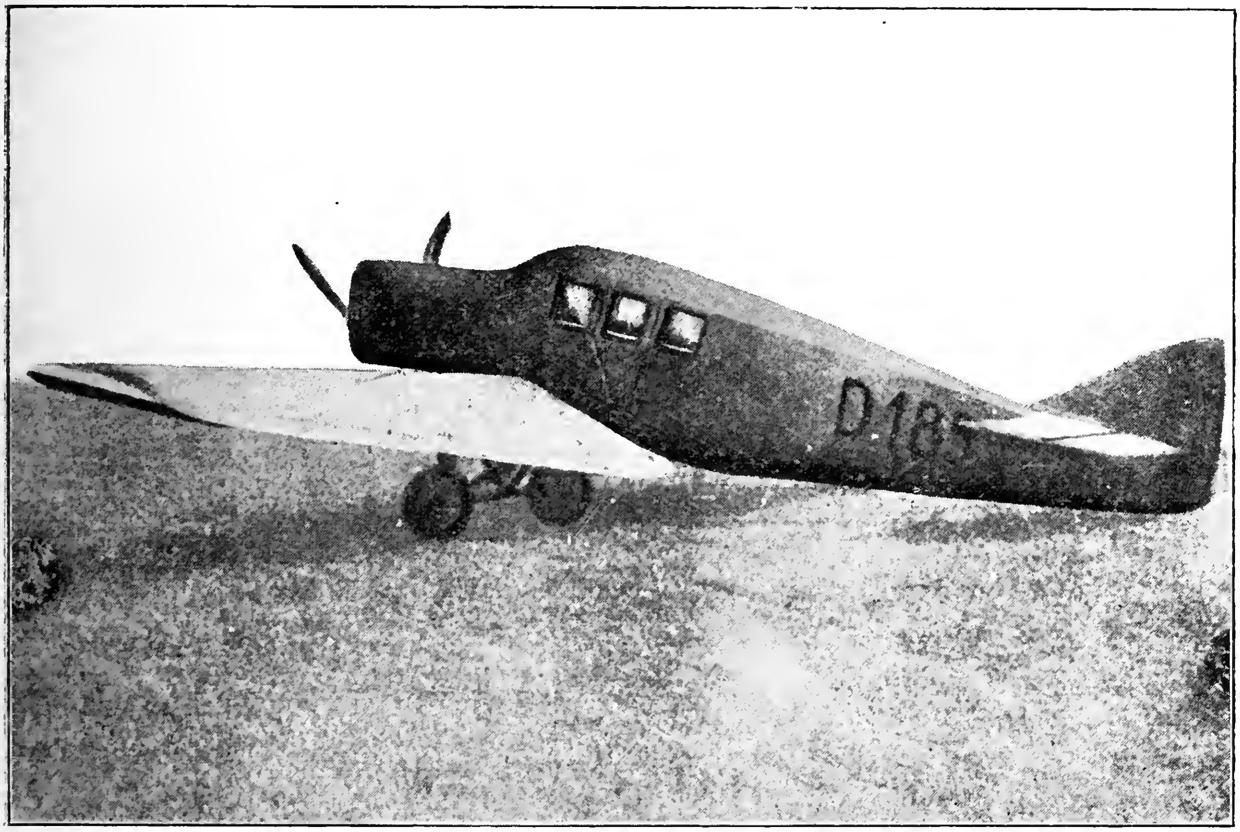
Reference to the photograph, Fig. 3, will at once impress the observer with the absence of struts, stays, king-posts, and other exposed accessories; in a word with the suppression of "parasite" and passive resistances. Further, the machine is of monoplane design, but in other respects, at first glance, similar to the ordinary and familiar designs of the past.

The absence of struts and stays to stiffen the wing spars at once raises a doubt as to the strength and factor of safety of such machines, or in other words

as to whether the wing spars are sufficiently strong in their capacity as cantilever beams to support the weight of the fuselage, engine, crew, etc., in the centre. The "Junker" firm have, however, so arranged the machine that only the bare necessities (consisting of the motor, crew and fuselage) are actually supported in the *centre* of the spars—all other weights, such as *fuel*, spares, tools, etc., are carried inside the wings, and consequently do not to the same extent affect the bending load on the main spares. So that the design in so far as the distribution of motor and fuel weight is concerned reverses the arrangement which charac-

FIG. 3.

A Type "C" machine.



An example of a German Type "C" machine, note the absence of struts, stays, etc.

terises Type "A" (with motors in the wings and fuel, etc., in the fuselage), but retains the advantage of distribution in weight, while at the same time effecting a reduction in head resistance. The importance of this compromise cannot be over estimated, and will again be referred to. In the immediate wake of the successful attempt to reduce head resistance we must now remark on the advantages in regard to the reduction in horse-power which this achievement allows of. The reduction in necessary horse-power indicates a further field of advantage in that the weight of the power plant, and more important still, the weight of the *fuel*, is reduced, which in turn results in a decrease in structure weight. To sum up then, the underlying principles adopted in the design allow of the use of a smaller machine than would at first sight appear possible; or conversely, permit of the carrying of a relatively high useful load (on a given total weight) by reason of the small horse-power required.

So far the advantages of the principles of this design are clearly apparent and the only points in doubt are, firstly, the strength of the cantilever spars, and

secondly, the possibility of the necessarily thick wing section being aerodynamically inefficient. As regards the first point, it should be observed in the absence of other more definite proof that "Junker" machines were built during the war to Government standard specifications and tested accordingly. (Factor of safety of 5.0 is allowed for in the design, which judged by Entente standards is low, but represents the normal German practice for its type.) As regards the efficiency of the thick wing section there may reasonably be some room for doubt when compared as an aerofoil with an ordinary "thin" section, but it must not be forgotten that the adoption of a thick wing section allows of the suppression off all struts and stays, and indeed this is in the case of the "Junker" the reason for its adoption. Add to this the actual and very remarkable performance of the latest "Junker" design and any doubt as to the *practical* efficiency of the "thick" wing must be discarded.

It may be well at this point to mention in passing, the adoption in the "Junker" of metal covered wings. This feature has no connection, as has sometimes been supposed, with the shortage of aeroplane fabric in Germany, but is employed firstly because metal sheet is far more durable than fabric (it retains its curve or section much better), and allows of a great saving of time during construction owing to the constantly changing wing section employed, and secondly, as additional strengthening for the wings themselves, the use of corrugated plates being naturally resorted to on account of "local rigidity."

We now come to the disadvantages of this type of design, and these in the light of present experience would appear to be of a practical rather than of a theoretical nature, for which it is necessary to rely on the statements of Junker pilots. Opinions as to the characteristics of the special wing construction seem to agree without exception as to the strength of the wings when in the air; fear is however expressed of the wings, owing to their too great "rigidity," breaking off "downwards" as the result of a bad landing. This point is one, perhaps, which should receive considerable attention, but is nevertheless largely capable of correction if specially designed and unusually flexible landing carriages are employed.

The next point is that of controllability—pilots stating that as a rule the machine is "difficult to land"—but this defect is apparently more visionary than real.

These remarks in relation to the strength and flying qualities of the Junker cantilever design, are inserted solely with a view to dispersing the scepticism with which many minds regard such departures from previous practice. At the same time it must be remembered that for our purpose we regard the Junker as a *type* only and not as an individual machine.

It should, however, not be forgotten that the realisation of metal construction, cantilever wings, has not been the result of haphazard chance, but represents an accumulation of painstaking research work in metallurgy and engineering science. The solution of this unique construction has been both slow and costly, moreover, it can safely be assumed that the full penalty for this development has not yet been paid.

So far the discussion has been confined to the Junker as it at present exists. It is the development of the machine which however is of peculiar interest, in so far as if the arguments in favour of the design are as well founded as they appear to be, and the practical disadvantages of the existing type overcome; then the constructional difficulties in the building of an enlarged machine of the general design would be very much less than in existing circumstances (with a comparatively small machine). Moreover, an increase in size, either with or without two or more engines, would not appreciably affect head resistance, since engines, gears, shafts, etc., could all be enclosed in the fuselage or within the wings themselves.

In no other type of design is it possible to trace such a set of circumstances in themselves so advantageous to the enlargement of aircraft, and at the same time so open to that compromise which is the essence of every successful machine.

It should be observed also that in the case of cantilever wing aeroplanes, the placing of the motors in the wings has also, as in the case of Type " A " machines, certain advantages in so far as the design and arrangement of the landing carriage is concerned—a point of no small significance in the case under consideration, when the question of bending load or the main spars is all important.

NOTE.—So far the foregoing observations on the three separate lines of development in giant aircraft (Types A, B and C) have been of a general nature, and as such applicable to both aeroplanes and seaplanes, and thus far the development of the giant aeroplane and seaplane has run a parallel course, with the same basic considerations in each case. Indeed, this must naturally be the case when one considers that the reason and necessity for increasing the size of aeroplanes is solely that of obtaining a greater useful load, whether as in the case of the seaplane in order to carry more fuel or as in the case of the aeroplane to carry a greater bomb load or armament. And since the fundamental considerations are the same for both the aeroplane and the seaplane we shall, if necessary, make use of the experience gained with both types if this should tend to assist our inquiry, which for the present is however concerned more closely with the aeroplane.

Summary of the General Features of A, B and C Types of Giant Aircraft.

In order to, as far as possible, arrive at a conclusion which will indicate the lines along which real progress and practical efficiency are to be obtained, the general features of the three " types " of aircraft (as distinct from secondary or individual peculiarities) must be considered from a definite standpoint which will embrace the fundamental principles at stake, general efficiency, and the actual application of theory to practical design.

In order, therefore, to crystallise the arguments for and against the various " types " of giant aircraft, the following table of " advantages " and " disadvantages " has been prepared, and shows at a glance the leading features attending the adoption of the " type " design for each of the three separate classes.

ADVANTAGES.	DISADVANTAGES.
Type A.	**Type A.**
1. Simplicity of design.	1. Excessive head resistance.
2. Simplicity of construction.	2. Poor performance and general inefficiency.
3. Cheapness of construction.	
4. No experimental work required.	
Type B.	**Type B.**
1. Increased efficiency.	1. Greater structure weight.
2. Reliability and accessibility.	2. Expense in provision of gearing.
	3. Limitation in size due to growth of structure weight.
Type C.	**Type C.**
1. Efficiency.	1. Expense of construction and experiment.
2. Durability of structure and " life " of the aeroplane.	2. Difficulties of construction.
3. Low running costs.	

From the table, which is representative within each classification of the general features of all the German machines under consideration, it is possible from super-

ficial considerations *only*, and in conjunction with the foregoing arguments, to say that :—

As regards Type " A " machines—

(1) The prevalence of this type is due mainly to military war requirements, and the possibility of rapid " production " due to constructional simplicity.

(2) That for commercial purposes giant machines of this type will be inefficient and unsatisfactory.

(3) That the ultimate abandonment of the type is certain.

As regards Type " B " machines—

(1) That improved efficiency and greater " reliability " as compared with Class " A " machines will give this type a temporary " commercial " vogue.

(2) That the expense of gearing, etc., for the special arrangement of power transmission, and the increasing difficulty of maintaining efficiency in very large examples of this type due to constructional limitations will eventually lead to its abandonment.

As regards Type " C " machines—

(1) Although in Germany represented by only three machines, that the efficiency, durability and general soundness of the underlying principles of its conception, indicate clearly a new and promising line of advance towards satisfactory giant machines.

(2) That the vast amount of technical skill, elaborate experiments and expense, which are necessary for the building up of this type, will render its development under normal conditions very slow.

We shall see later how accessory circumstances and minor considerations affect or modify these initial conclusions.

In the meantime we will proceed to review the characteristics of some of the *minor* features peculiar to each " type " or class of machine, in order that before coming to any definite conclusion we may see more clearly the balance of compromise observable in German machines as between the desire that inspires conception and the realisation in practice of each " type " design.

NOTE.—In the following chapter on " Minor features of German Giant Aircraft " we shall omit consideration of the details of giant seaplanes, but shall reserve the right to refer to them again, if necessary, in our conclusions and deductions.

III

MINOR FEATURES OF GERMAN GIANT AIRCRAFT.

CONTENTS.

2. **Performance.**

Section (*a*) German giant aircraft performances.
,, (*b*) Range and duration.
,, (*c*) Controllability and stability, with note on the possible advantages of "thick" wing sections.

3. **Military Features.**

Section (*a*) Crew and defence armament.
,, (*b*) Bomb armament.
,, (*c*) "Maintenance."

4. **Power Plant and Installation.**

Section (*a*) Arrangement.
,, (*b*) Gearing, gear drives, etc.
,, (*c*) Fuel storage.
,, (*d*) "Forced induction."

(1) CONSTRUCTION. SECTION (*a*) WINGS.

Choice of Wing Section.

The German designer has probably a very much larger choice of wing sections whose characteristics are definitely established than in the case of British or French designers. Reference to the "Technische Bericht" (Charlottenburg) will show this, and in addition it should be remembered that there are a number of other well equipped laboratories which undertake aeronautical research and test work. The choice of a wing section then is unusually large, and in consequence giant machines exhibit a wide range of differences. In general, however, the sections adopted are relatively heavily cambered, and within the category of "high-lift" wings. An extreme case is that of the "Junker" with its cantilever spars and heavy camber, but with the wing section becoming naturally less deep towards the wing tips. The Junker wing, however, deserves special consideration and should be treated separately.

Since, however, the choice of wing sections is a matter largely dependent on the individual circumstances of each particular case, it is not necessary to include an examination of this matter in our survey. As regards the wing sections it remains only to add that even in the case of the largest giant machines there is no room between the surfaces of the wing—except in the special case of cantilever wings—to accommodate fuel or any other substance.

Wing Surfaces of "Type A and B" Machines.

All the "Type A" machines which we have had under review are equipped with "thin" section wings, constructed entirely of wood. The wing spars (partly owing to the shortage of wood) are in most cases of composite construction and usually of simple "box" form or section. Attempts to build spars on the "Zeppelin girder" system from short lengths of wood do not appear to have been very successful, though this method of construction has been tried.

A certain amount of metal work is to be found in the tail planes of many of the giant machines, but generally speaking, the construction of the wings and even the inter-plane struts is of wood.

The wing bracing of Types A and B is usually carried out with stranded cable, and the lift wires are as a rule not duplicated, though cross bracing is fitted between the strut bays. Bracing cables as a rule are carried right round the main spars and spliced, so as to form a loop. This form of construction, which

is perhaps somewhat crude, has the effect of simplifying considerably the main spar metal fittings.

The wings of "Type A" giant machines seem to give very little trouble in spite of their comparatively small factor of safety. On the other hand, the fact that the main weights (due to the motors being fitted in the wings) are widely distributed is a great advantage so far as the construction of the wings themselves is concerned.

Wing Surfaces and Structure of "Type B" Machines.

The same general remarks are applicable in regard to the structure of the wings as in the case of "Type A" machines. In this case, however, owing to the concentration of weight in the centre of the machine, a great deal of difficulty has been experienced with the wing structures. In at least one instance a large "Type B" machine had to be abandoned on account of lack of rigidity in the wings. (Factor of safety 4.0.) This is a point of very great importance, and already indicates the fact that in point of size the existing "Type B" has reached—if not passed—the practical limits of construction. It is interesting to note that in this case practice coincides exactly with theory. Obviously, therefore, we cannot expect to see a further development of this type of machine without some radical change in weight distribution, such as will again permit of the wing-structure being made sufficiently robust for practical purposes.

Wings and Wing-structure of "Type C" Machines.

The construction of the cantilever wing of Prof. Junkers is in almost all respects entirely different from the wood-and-fabric wing construction of the "Types A and B." No wood is employed. In place of the old standard arrangement of two main wooden spars, there are nine metal tube spars. No ribs are used except at the loading edge of the plane, and the wing surfaces are of corrugated duralumin sheet. The detail description of this wing is, however, a matter for separate study. We require only to note that the durability of the all-metal wing is infinitely superior to its fabric-covered predecessors, that the construction is simple, and that the wings have given good results in practice.

Being very deep at the roots, there is ample room inside the wing surface for the storage of petrol, spare parts, etc. It is possible, in fact, with this type of wing to arrange the weight distribution in almost any manner desired, by the simple process of altering the fuel-tank position inside the wings. It is as well to repeat that in this case the weight distribution can be arranged as required, without in any way affecting the head resistance of the machine. In the case of very large machines, it is impossible to over-estimate the importance of this fact.

General Remarks on Wing Structure of German Giant Machines.

It may be said that so far as the wings of "Type A and B" machines are concerned, German practice differs but little, except in minor details, from the usual practice in Entente countries. The main considerations have in each case been the same, and it remains only to say that the German products are somewhat crude and ill-finished when compared to Entente standards, but at the same time this is clearly traceable to the serious shortage of all raw materials.

The same cannot be said of the German all-metal cantilever wings. These are at present in a class apart, and represent an achievement in engineering science to which there is no parallel in Entente countries. Moreover, it would not be easy to imitate or improve upon the existing German model without a considerable amount of expenditure in experimental work and careful research into the special properties of aluminium alloys.

It might be as well to remark that the Junkers firm have made great efforts to employ steel in the construction of their cantilever wings, but without success; the principal disadvantages being due to lack of local rigidity in the lighter parts, and also to rapid deterioration from exposure to normal weather conditions. Obviously, however, the disadvantages attending the employment of steel tend to diminish as the size of the machine—and in consequence the size of the individual parts—increases.

Section *(b)*, Fuselage or Body (Giant Machines).

The variation in the methods of construction employed for the bodies of German Giant machines is so large as to make it impossible to distinguish any one particularly satisfactory or exceptional type of design.

If we include the Junker all-metal fuselage, we have, in addition to this example, fuselages constructed of: (*a*) Wood veneer, (*b*) wood and wire bracing, (*c*) composite steel and wood with wire bracing, and (*d*) steel tube. It is difficult to say which of these various designs is the best or most promising. It seems, however, that the very large wood veneer fuselages are extremely heavy, and it is doubtful if they can be successfully employed for very big machines.

As regards the **all-metal** fuselage of the Junker, it is at present impossible to say whether or not this form of construction would be satisfactory in very large examples. Actually there is reason to suppose that the special form of construction employed in the present machine is not over-robust, but it is possible that this defect is due to the difficulty of obtaining (in Germany) reliable duralumin.

There is a tendency in the larger German Giants to reduce the length of the fuselage, and to substitute a large tail fin instead, with the object of cutting down weight. This practice is a questionable one, and usually results in difficulty with the control surfaces and tail fin. This particular tendency is, however, more marked in the large "Type B" machines, where the weight of the fuselage and its contents are in any case higher than is desirable. As regards the steel-constructed fuselages, we note an absence of any special fittings at the tube joints. German aeroplane constructors apparently have a good deal of faith in the ordinary process of acetylene-welding, although as a general rule the workmanship displayed by the welded joints is not of a very high order. The usual system of welded steel construction is also ill-adapted to repairs or replacements.

In general the construction of the bodies for giant aeroplanes is simple and cheap, the workmanship is indifferent, and the structural design of no particular merit.

Section *(c)*, Landing Carriages.

We have in the introduction remarked that German giant machines were primarily designed for strategic purposes. They were not, therefore, expected to work from improvised aerodromes such as must necessarily be used when close up to the Front. We find, therefore, that the landing carriages of the German giant machines are as a rule of very indifferent design compared with Entente standards, and quite incapable of negotiating bad ground.

The wheels are, generally speaking, absurdly small and somewhat numerous. In the majority of cases, due to the small diameter of the wheels, arrangements are made to allow of additional wheels being fitted to the same axles for use in wet weather and on soft ground. Even so, in many cases designers fit auxiliary front wheels on the front of the fuselage, in order to guard against the likelihood of their machines "turning over" forwards when the wheels encounter obstacles on soft ground. German giant landing carriages are therefore, as a rule, cumber-

some and have a high relative head resistance, due to the auxiliary wheels in front.

It should be remarked that the small size of the main wheels may have been to a large extent due to the shortage of pneumatic tyres and the impossibility of obtaining large tyres suitable for big diameter aeroplane wheels. At all events, from a practical point of view, German giant landing carriages are inferior to those of the corresponding Entente machines.

There is nothing remarkable about the shock-absorbing devices employed or the general design of landing carriage struts or framework.

The landing carriage of the newest Junker machine ("Type C") is remarkable in that while the design is that of the simple and familiar V type, the arrangement differs from standard practice in that both the V struts are themselves shock-absorbers. This arrangement, which has been adopted on account of the long unsupported length of the wings, allows the axle to travel both upwards and backwards when negotiating rough ground.

Note.—During the last two years of the war, only machines actually employed at the Front were fitted with pneumatic tyres. Training and practice machines of all types were equipped with wooden-rimmed wheels.

Section (*d*), Control Surfaces.

The control surfaces of German giant machines are almost always "balanced," sometimes by the simple addition of a small portion of control surface which projects forward and in front of the hinge axis, and sometimes by the addition of a small auxiliary surface.

The newest giants are fitted with adjustable "fixed" tail planes in imitation of the Entente machines.

All controls are as a rule spring compensated and so fitted as to be readily adjustable from the pilot's seat. These fittings are of a simple nature and contain nothing new or novel to ordinary standard practice.

It is interesting to observe that in nearly all cases the elevators are built on a continuous spar or tube in such a way, therefore, that the right and left hand portions of the elevator cannot (when the control wires become slack) move independently. This method of construction, although slightly heavier than the more usual system of "split" elevators, has the great advantage that while it re-duplicates the control wiring it also serves to damp out torsional vibration in the fuselage and to prevent its taking place.

While it is not possible, without actual personal experience, to make any statement as to the efficiency of the "giant controls," it is a fact that pilots of the large "Type A" machines rely more on their engine throttle controls than on the ailerons when flying in bad weather. At the same time the actual area of the German giant control surfaces is as a rule proportionately very much less than in Entente countries.

The proportional "part weights" of German giant control surfaces and control gear are, generally speaking, a good deal heavier than might be anticipated. This is to some extent due to the fact that German designers have a tendency to build short fuselages in order to save weight in the fuselage itself. This feature naturally increases considerably the weight of the control surface, tail fin, etc., which have to be made correspondingly larger.

Section (*e*), Note on "Factor of Safety."

During the war, and therefore applicable to all German machines at present

under consideration, the following were the official "factors of safety" according to Government specifications:—

E and D Types ...	...	Factor of 5.0
C and G ,, ...	...	,, 4.5
R ,, ...	...	,, 4.0 (giant machines)

It is safe to assume that these factors were rigorously enforced, and indeed in the case of German "fighters" the specified factors must have been as a rule very considerably exceeded.

So far as can be ascertained, few if any cases of "failure" in the air occurred with giant or "R" machines. In connection with this it must be again remarked that the control surfaces, and particularly the elevator surfaces, in German giant machines are small. It is not possible to determine, however, whether or not this is due to deliberate intention with a view to preventing pilots from imposing undue strains on their machines from too violent use of the elevator. With a reduced factor of safety this point is of considerable importance, but in any case in the light of German experience a factor of safety of 4.0 in the case of giant machines, appears to be quite sufficient for all normal purposes.

Section (*f*), Limits of Construction.

The following table gives some indication of the composition of the total weight in giant machines of "Type A" and "Type B." It shows the percentage weights of the "glider" (that is to say, the aeroplane structure), the "power plant," including propeller gears and transmission, and also the "load" and "fuel."

PERCENTAGE WEIGHTS IN RELATION TO TOTAL WEIGHT, GERMAN "GIANT" MACHINES.

"Type."	No. of Motors.	H.P.	Glider Wt. %	Power Plant %	Useful Load %	Load %	Fuel %	Total Wt. in kg.
"Type A"	3 motors	735	45.5	19.6	34.9	23.9	11.0	10,203
"Type A"	4 motors	1072	43.2	23.8	33.0	15.7	17.3	11,460
"Type A"	4 motors	1072	39.5	27.1	33.4	17.3	16.1	11,693
Mean values ...		...	44.1	23.5	33.8	18.9	14.8	11,119
"Type B"	6 motors	1228	41.3	27.6	31.1	14.6	16.5	12,953
"Type B"	6 motors	1228	40.1	27.2	32.7	16.3	16.4	13,035
Mean values ...		...	40.7	27.4	31.9	15.4	16.4	12,994

Any discussion of these figures (whose accuracy can be relied upon) would be controversial, and for our purpose of no great value. We require to note, however, that the glider weight of the "Type B" machines is less than in the case of the "Type A" machines. This fact is not easily accounted for. It however must be remarked that the "Type B" machines are of more recent construction and that their total weight is greater.

The additional weight of the power plant of the "Type B" machines is clearly apparent (the figures include the propellers, gears and shafting).

In all other particulars it will be observed that the "Type B" weight percentages are inferior to those of "Type A" design. It remains to be seen how these circumstances are either reflected or compensated for in "performance" results.

As regards the proportion of useful load and fuel in existing giant machines of both types, it is necessary to insist that these are considerably more satisfactory than has been imputed by aeronautical theorists. In any case it is quite clear that as regards weight proportions, the giant machines in question are far from any "limits" which theoretical consideration may suggest. This circumstance is extremely important, particularly when it is remembered that the materials employed are for the most part inferior, and that the designers were heavily handicapped by the low power of the individual motor units.

(To be continued.)

CORRESPONDENCE.

To the Editor of the Aëronautical Journal.

. Dear Sir,—I have read with great interest Mr. Thomson's comments on my paper on the flying of twin-engined aeroplanes. Among other things he refers to the effect on the fins of twin-engined aeroplanes when the airscrews revolve inwards.

With the standard Handley Page 0/400 and Vickers Vimy aeroplanes, in which the airscrews revolve the same way, there is a definite turning tendency noticeable. I believe that some of the early Handley Page 0/400's had inward turning airscrews, and though I have no first-hand experience, I have been told by a pilot who has flown one that, as would be expected, there was no turning tendency. So far as I know, the Vimy was designed after Messrs. Rolls-Royce had standardised the sense of rotation of their engine.

Mr. Thomson states that a Vimy proved capable of flying on the port motor (an inward turning engine), but failed to fly level on the starboard one, owing to the nose having to be put down and a greater speed attained to overcome the turning tendency.

As far as my knowledge of the Vickers Vimy goes, the port engine turns outwards. If then "starboard" be substituted for "port," I have not noticed this to any extent when flying a Vimy, although I have not measured the rudder forces when flying on the starboard and port engines with the standard fins.

I think it may be for this reason. Take the case of a standard Vimy, flying on the starboard engine which turns inwards, the port engine being cut out. The starboard engine brings into play a couple tending to turn the aeroplane to port; the rudder is put over to starboard to counteract this, but at the same time produces an unbalanced lateral force, which, if the wings are to be held level, can only be balanced by the aeroplane sideslipping to port. The slipstream of the starboard engine, which would normally be exerting a force on the fin tending to counteract the turning tendency, is diverted by the sideslip; thus the fin is not affected, and the value of the inward rotating slipstream is practically lost. If this is so, the case for inward turning airscrews is considerably weakened.

I am afraid I have no specific information on the control at low speeds of the early aeroplanes built at Farnborough, but general experience would seem to suggest that with the present form of control surfaces, abnormally good control at low speeds is only to be had by making the control at high speeds excessively heavy.

Yours faithfully,

R. M. Hill.

Experimental Section,
Royal Aircraft Establishment,
S. Farnborough.

REVIEWS.

A Treatise on Airscrews. Whyrill E. Park, A.R.C.Sc.

This work is frankly empirical and aims at showing how to design a propeller for a given purpose rather than examining how a propeller functions. A theoretical or mathematical treatise may be judged by itself, but the true value of an empirical work must depend on the experience and authority of the writer. We understand Mr. Park was the designer for Lang Propellers Ltd. towards the end of the war, and in so far as this work embodies the experience of that firm, the book should within limits be a useful one for designers.

It is well written and sound where the author deals with the drawing office design of a propeller using the simple blade element theory, and in the section dealing with construction. Elsewhere, in the treatment of the effect of obstructions, tandem propellers, variable pitch propellers and all the important side issues, the treatment is weak and in many cases amounts to little more than a mention. The absence of a chapter dealing in detail with the effect of gearing is an omission.

One serious error we must point out. The author apparently has not grasped the fundamental conceptions underlying the inflow theory. He has confused the term "slipstream" with the unfortunate term "slip" used in some early reports of the Advisory Committee, a term very similar in meaning to that used in marine engineering.

The slipstream velocity he states to be constant and equal to the velocity of translation at no thrust. His inflow is therefore taken as one half the difference between the no-thrust velocity and the actual aircraft velocity. Thus, in the example which he worked out to compare the results given by the simple theory and what he takes as the inflow theory, he obtains an average *inflow* of about 39 feet per second.

The difference in horse-power absorbed and efficiency as between the two methods, says the author, is "alarming." We agree, but the alarming result is due not to the inflow theory but to the author's misunderstanding. Worked out on the inflow theory as commonly accepted and understood, the inflow velocity in this particular example should be about 9-10 feet per second. This mistake carries through the book and vitiates the already weak treatment of tandem propellers.

It is also somewhat disturbing to be told on page 39 that the slipstream $V_1 + v$ is constant and on page 46 that inflow velocity is directly proportional to the translational velocity.

Had the book been limited to construction strength and to the simple theory of design we could have recommended it. As it is we can only recommend it to those who have sufficient experience with propeller design and theories to be able to distinguish the good from the bad and to apprise the value of the empirical rules given.

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All communications should be addressed to the Editor.

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Notices of the Royal Aëronautical Society.

Election of Members.

The following members were elected at a Council Meeting held on Tuesday, February 15th, in the various grades as shown :—

Associate Fellows.—Flying Officer G. Mornington Bryer, A.F.C., J. D. Campbell, B.Sc., H. B. Wyn Evans, M.I.N.A., Shou-Heng-Huang, Flight Lieut. A. J. Osborn, Lieut. C. St. Clair Penny, Squadron Leader R. G. Parry, D.S.O., E. T. Robins.

Students.—A. N. Clifton, C. Daniel, E. M. Farris, W. H. Rossiter, V. S. Thompson, M. W. Wood.

Foreign Members.—R. A. Hendy, Lieut.-Col. H. St. Clair Smallwood, R.A.F.

Lectures.

The remaining lectures of the present Session will take place as follows :—

March 3rd.—"Parachutes," by Major T. Orde-Lees, O.B.E., A.F.C.; "Airship Fabrics," by Mr. J. W. W. Dyer; Chairman, Air Commodore E. M. Maitland, C.M.G., D.S.O., A.F.C., Associate Fellow.

March 17th.—"Flying Boat Construction," by Capt. D. Nicolson, Associate Fellow.

Obituary.

It is with great regret that the death of Colonel James Smith Park, M.V.O., is announced. Colonel Smith Park was one of the most active members of the Committee of the Scottish Branch, on which he had served since its inception.

New Member of Council.

A letter of resignation from the Council was received at the February Council Meeting from Lieut.-Colonel A. Burgoyne, M.P. It was decided to accept Col. Burgoyne's resignation with great regret, and Colonel the Master of Sempill, A.F.C., was unanimously co-opted to serve in his stead pending the next elections.

Council.

At their last meeting the Council completed their consideration of the Secretary's draft amendments to the Rules which will now, together with the new

regulations for the admission of Fellows and Associate Fellows, be laid before the Annual General Meeting for adoption at 5.0 p.m. on Thursday, March 31st.

The statement of accounts for the six months ending December 31st, 1920, was also passed at the same meeting, and these, together with the Council's Annual Report on the state of the Society, will be found on another page.

Early History.

The Secretary is glad to be able to announce that he has been able lately to obtain two copies of the first paper to be read before the Society on its formation, which he has placed in the Library. This was a paper read by Mr. Fred Brearey, the original Honorary Secretary, at Stafford House, on February 28th, 1866, when the Duke of Sutherland occupied the Chair. The occasion was the second Council Meeting (the first having been held at Argyll Lodge on January 12th of the same year), and the paper contains a suggested programme for the proceedings of the Society. The order for its printing and circulation to members has been found in the original minute book in the Society's possession. It is a paper-bound pamphlet of 4 octavo pages, and is believed to be very rare. The Secretary had already a copy in his own possession, but had not previously been able to trace one among the Society's records. He feels that members will be glad to have this interesting historical addition to the Library. The first paper read before a meeting of the members as a whole was, of course, F. H. Wenham's paper on "Aerial Locomotion," read at the Royal Society of Arts on June 27th, also in 1866, which has been reprinted as the second volume of the "Aeronautical Classics."

Donations.

The Council desire to acknowledge with grateful thanks the gift from Mrs. Lawrence Hargrave of a large number of note-books, papers, negatives and lantern slides belonging to her late husband. Lawrence Hargrave did a large amount of most valuable experimental work in Australia, mainly in connection with kites, between the years 1884 and 1908, and is deservedly considered one of the most important early pioneers of aviation. He was born on January 29th, 1850, and died on July 6th, 1915. Arrangements have been made for these records to be carefully gone through with a view to the extraction of any data which should be put on historical record and which has not been previously published.

The Council desire also to acknowledge the receipt from Mr. Alma Baker, Honorary Member, of a presentation copy of his "Souvenir of the Australian and Malaya Battleplanes, 1914-1918," which has been prepared as a record of the efforts made to assist the Home Government during the war by presenting aeroplanes to the Royal Flying Corps and Royal Air Force, as a result of which sufficient money was subscribed to purchase 94 aeroplanes.

Manchester Association of Engineers.

At the request of the Manchester Association of Engineers, it has been arranged for the Chairman (Air Commodore H. R. M. Brooke-Popham, C.B., C.M.G., D.S.O., A.F.C.) to read a paper on "Some Problems in the Design and Operation of Aircraft" before the members of that body at 7.0 p.m. on Wednesday evening, March 2nd.

Journal.

Copies of the following numbers of the Journal are urgently required, and the Secretary would be grateful if any member who does not desire to retain his copies for filing purposes would be kind enough to return them as these numbers are quite out of print:—January, March, April and June, 1920.

Library.

The following books have been placed in the Society's Library :—" Applied Aerodynamics " by Dr. L. Bairstow, and " The Design of Screw Propellers for Aircraft " by Dr. H. C. Watts.

Membership Cards.

Cards of membership are being enclosed in the envelopes containing the notice of the Annual General Meeting to each member who has paid his subscription. Those who have not yet forwarded their subscriptions for this year will receive cards on receipt of the amount due.

Arrangements for the Month.

March 2nd, 7.0 p.m.—Chairman's Lecture on " Some Problems in the Design and Operation of Aircraft " before the Manchester Association of Engineers.

March 3rd, 5.0 p.m.—*Lectures* : " Parachutes " by Major T. Orde-Lees, O.B.E., A.F.C. ; " Airship Fabrics " by Mr. J. W. W. Dyer.
Chairman : Air Commodore E. M. Maitland, C.M.G., D.S.O., A.F.C.

March 15th, 4.0 p.m.—Lectures and Publications Committee Meeting.

,, ,, 4.30 p.m.—Candidates Qualifications Committee.

,, ,, 5.0 p.m.—Council Meeting.

March 17th, 5.30 p.m.—*Lecture* : " Flying Boat Construction " by Capt. D. Nicolson, Associate Fellow.

March 31st, 5.0 p.m.—**Annual General Meeting** in the Society's Offices.

W. Lockwood Marsh, *Secretary.*

THE ROYAL AERONAUTICAL SOCIETY.

Annual Report of the Council, 1920-21.

In presenting their 56th Annual Report the Council have the honour to announce that during the year His Royal Highness the Duke of York, K.G., graciously consented to become an additional Patron of the Society. Air-Marshal Sir Hugh Trenchard, Bart., K.C.B., D.S.O., and Commander J. C. Hunsaker, U.S.N. (C.C.), were elected Honorary Fellows in June. The Council for the year consisted of the following members :—

Chairman : Air Commodore H. R. M. Brooke-Popham, C.B., C.M.G., D.S.O., A.F.C.

Vice-Chairman : Brigadier-General R. K. Bagnall-Wild, C.M.G., C.B.E.

Mr. A. E. Berriman, Major F. H. Bramwell, Lieut.-Col. A. H. Burgoyne, M.P., Wing Commander Cave-Browne-Cave, C.B.E., Sir Mackenzie Chalmers, K.C.B., C.S.I., Sir Robert Hadfield, F.R.S., Prof. B. Melvill Jones, A.F.C., Major A. R. Low, Lieut.-Col. A. Ogilvie, C.B.E., Lieut.-Col. M. O'Gorman, Mr. F. Handley Page, C.B.E., Mr. A. J. Sutton Pippard, D.Sc., Mr. A. V. Roe, O.B.E., Major-General Sir R. M. Ruck, K.B.E., C.B., C.M.G., Lieut.-Col. H. T. Tizard, A.F.C., Mr. G. Holt Thomas, Brig.-Gen. J. G. Weir, C.M.G., Major H. E. Wimperis, O.B.E.

Honorary Treasurer : Mr. A. E. Turner.

Lieutenant-Colonel the Master of Sempill, A.F.C., was co-opted a Member in place of Lieutenant-Colonel A. Burgoyne, M.P., resigned, in January. Major-General Sir R. M. Ruck, K.B.E., C.B., C.M.G., was elected Vice-President of the Society in November.

The Council feel that they may congratulate Members on the well-being of the Society in spite of the difficulty of the period which is being passed through. There is little doubt that its status has steadily improved during the year, although activities have been necessarily restricted owing to the serious financial position which was disclosed at the beginning of the year. The present situation in this regard is dealt with in some detail in a later paragraph, but it may be said here that the condition of affairs is very considerably improved as a result of making every effort to exercise economy, and that the future may be faced with some confidence in the belief that before the end of the coming financial year the Society will definitely have been placed on a sound financial basis so far as current expenses are concerned, though this means that no increase in the present limited activities can take place. It has at the same time, however, been found necessary to bring forward a deficit in the Balance Sheet of £1,542 19s. 11d. There is every reason to hope that in future it will be possible to make the revenue cover expenditure, but there is no doubt that the financial position will not be thoroughly satisfactory until an Endowment Fund, amounting to some £2,000, has been raised, and the advisability of opening a subscription list to this end is under consideration.

In spite of the necessity for economy, the year has seen a revival of certain methods of bringing members closer together by the holding of an Annual Dinner, at which the President took the Chair, and by the arranging of a visit to the Aerodynamics' Department of the National Physical Laboratory. The provision of a room for the use of members at the Olympia Aero Show also proved of convenience to members visiting the Show.

Membership.

In spite of the increase of subscriptions, by 50 per cent. in the case of old members and by 100 per cent. in the case of members elected subsequent to June 1st, 1920, the membership has been well maintained. This numbered 1,146 in January, 1920, and on January 1st, 1921, stood at 1,002. A gratifying feature is that although inevitably a number of members have found themselves compelled to resign owing to the necessity of cutting down their subscription lists, there is a steady inflow of new members in all grades numbering from 10 to 15 per month.

Scottish Branch.

The membership of the Scottish Branch numbered 156 on January 1st, 1920, and the year has been one of considerable activity, of which a full report was published in the October number of the Aeronautical Journal. A large number of valuable lectures have been given, at which the average attendance has been about 175. The members also paid a visit to Messrs. Beardmore's airship shed at Inchinnan during the autumn, when they had an opportunity of inspecting the rigid airship R.36 under construction. The Chairman of the Scottish Branch, Lord Invernairn, received the honour of elevation to the Peerage in the 1921 New Year's Honours List. The Annual Dinner in London in November afforded a welcome opportunity for members in England to meet the members of the Scottish Branch, who were well represented on that occasion. The Council desire to express their gratitude to the members of the Scottish Executive for their untiring efforts to further the objects of the Society in the North, which have been rewarded by such remarkable success and enthusiasm. It is hoped to publish in a forthcoming number of the Journal the Second Annual Report of this Branch, whose year terminates on May 31st.

Cambridge University Aeronautical Society.

The Council would like to take the opportunity of offering their congratulations to the Cambridge University Aeronautical Society, which became affiliated to the Royal Aeronautical Society during the year, on the remarkable success they have achieved in forming so flourishing a Society in Cambridge. Their lecture programme during the year has been one of the greatest interest and importance, to which a number of technical members of the Society have contributed, and the Cambridge Society is much to be congratulated on the enterprise and enthusiasm of their President (Mr. H. A. Mettam) and Secretary (Mr. O. E. Simmonds).

The Technical Terms Committee.

With a view to better co-ordination, and also owing to a difficulty in providing the necessary money for printing and circulating a revised edition of the "Glossary of Aeronautical Terms," it was in November decided to offer the services of the Society's Technical Terms Committee to the British Engineering Standards Association for the purpose of completing the revision of the Glossary. The Council are indebted to the Association for willingly falling in with the suggestion made, and this Committee is now working under the auspices of that body. It has been arranged that full acknowledgment of the work of the Society shall continue to appear in the new edition of the Glossary.

Representation on Other Bodies.

The Council desire to tender their thanks to the following gentlemen for kindly consenting to serve as the Society's representatives on other bodies :—

Conjoint Board of Scientific Societies.—Major-General Sir R. M. Ruck.
Aeronautical Research Committee.—Lieut.-Col. A. Ogilvie.

Advisory Committee on Aeronautical Education.—Dr. R. Mullineux Walmsley.

British Engineering Standards Association.—Lieut.-Col. M. O'Gorman.

Air Ministry Load Factor Committee.—Lieut.-Col. M. O'Gorman and Capt. G. de Havilland.

British Science Guild.—Major A. R. Low.

Lectures to Other Bodies.

During the year a number of lectures on aeronautical subjects have been arranged by the Society to other bodies both in London and the provinces. A course of six lectures on "Aircraft Steels and Materials" was delivered to the students of Sheffield University during October and November by Brigadier-General Bagnall-Wild, Dr. L. Aitchison, Captain W. A. Thain, Mr. A. J. Rowledge, and Mr. A. A. Remington. Two popular lectures on the development of commercial aeroplanes and airships were delivered in the Fulham Public Library at the request of the Fulham Borough Council in November and February by Captain F. M. Green and the Secretary respectively. At the request of the Higher Production Council, two lectures were delivered at Olympia in February during the "Daily Mail" Efficiency Exhibition by Mr. H. White Smith on "Commercial Aeroplane and Seaplane Transport," and by Mr. C. I. Campbell on "Commercial Airship Transport." The Chairman also delivered a lecture on "Some Problems in the Design and Operation of Aircraft" before the Manchester Society of Engineers on March 2nd, 1921.

At the request of the Air Ministry the Society arranged a series of lectures at the Aero Show at Olympia in July by Captain P. D. Acland, Mr. Griffith Brewer, Captain F. M. Green, Captain D. Nicolson, Flight-Lieut. J. E. M. Pritchard and Major H. E. Wimperis.

The Council desire to express their thanks to all these gentlemen for kindly giving their services on these occasions.

Wilbur Wright Lecture.

The annual Wilbur Wright lecture was delivered at the Central Hall, Westminster, before an audience of about 800 people by Commander J. C. Hunsaker, U.S.N. (C.C.), the subject being "Naval Architecture in Aeronautics." His Royal Highness the Duke of York honoured the Society with his presence in the Chair.

Meetings.

With the commencement of the 56th Session in October, 1920, it was decided to hold meetings in the afternoon in place of the evening as formerly, which has appeared on the whole to be a welcome innovation. The practice of certain other institutions, and an old practice of the Society, of having more than one paper read at some meetings was adopted, and also in most cases abstracts only were read. These experiments have, however, aroused some discussion and a reversion to the practice of having only one paper at each meeting has been decided upon. The full list of papers read since the last Report is as follows :—

1920.

April 14.—Subject, "Transcontinental Flying"; Lecturer, Capt. P. D. Acland; Chairman, Major-General E. D. Swinton, C.B., D.S.O.

April 28.—Subject, "Aerial Transport from a Business Point of View"; Lecturer, Major-General Sir Sefton Brancker, K.C.B.; Chairman, Major-General Sir F. H. Sykes, G.B.E., K.C.B.

May 12.—Subject, "Notes on Flying Boat Hulls"; Lecturer, Major Linton Hope, M.I.N.A.; Chairman, Prof. L. Bairstow, C.B.E., F.R.S.

May 26.—Subject, "Some Points of Importance in the Work of the Advisory Committee for Aeronautics"; Lecturer, Sir Richard Glazebrook, K.C.B., F.R.S.; Chairman, Major-General Sir E. L. Ellington, K.C.B., C.M.G., C.B.E.

56th Session.

October 7.—Subject, "Civil Aviation"; Lecturer, Major-General Sir F. H. Sykes, G.B.E., K.C.B.; Chairman, Rt. Hon. A. H. Illingworth, M.P.

October 21.—Subject, "Comparison of the Flying Qualities of Single and Twin-engined Aeroplanes"; Lecturer, Squadron Leader R. M. Hill, M.C., A.F.C.; Chairman, Major-General Sir Sefton Brancker, K.C.B.

,, Subject, "Night Flying"; Lecturer, Major Cecil Baker, D.F.C., A.F.C.

November 4.—Subject, "The Human Machine in Relation to Flying"; Lecturer, Wing Commander Flack, C.B.E.; Chairman, Sir Humphry Rolleston, K.C.B., F.R.C.P.

November 18.—Subject, "The Problem of the Helicopter"; Lecturer, Mons. Louis Damblanc; Chairman, Air Vice-Marshal Sir E. L. Ellington, K.C.B.

December 2.—Subject, "Airship Mooring"; Lecturer, Flight Lieut. F. L. C. Butcher.

,, Subject, "Airship Piloting"; Lecturer, Maj. G. H. Scott, C.B.E., A.F.C.; Chairman, Air Marshal Sir H. M. Trenchard, Bart., K.C.B.

December 16.—Subject, "Possible Developments in Aircraft Engines"; Lecturer, H. R. Ricardo, A.M.Inst.C.E., M.I.Aut.E.

,, Subject, "Installation of Aeroplane Engines"; Lecturer, A. J. Rowledge, A.M.I.Mech.E., M.I.Aut.E.; Chairman, Lieut.-Col. H. T. Tizard, A.F.C.

1921.

January 20.—Subject, "The Cost of Air-Ton Miles Compared with Other Forms of Transport"; Lecturer, Rt. Hon. Lord Montagu of Beaulieu, C.S.I., M.P.; Chairman, Rt. Hon. Lord Weir of Eastwood.

February 3.—Subject, "Ground Engineering"; Lecturer, Wing Commander H. W. S. Outram, C.B.E.

,, Subject, "Meteorology in the Service of Aviation"; Lecturer, Major Gordon Dobson; Chairman, Dr. G. C. Simpson, C.B.E., F.R.S.

February 17.—Subject, "The Handley Page Wing"; Lecturer, Mr. F. Handley Page, C.B.E.; Chairman, Sir Joseph Petavel, K.B.E., F.R.S.

March 3.—Subject, "Airship Fabrics"; Lecturer, Mr. J. W. W. Dyer.

,, Subject, "Parachutes"; Lecturer, Major T. Ord Lees, O.B.E., A.F.C.; Chairman, Air Commodore E. M. Maitland, C.M.G., D.S.O., A.F.C.

March 17.—Subject, "Flying Boat Construction"; Lecturer, Capt. D. Nicolson.

Juvenile Lecture.

January 11.—Subject, "Airship Flights of Fact and Fancy"; Lecturer, Air Commodore E. M. Maitland, C.M.G., D.S.O., A.F.C.; Chairman, Lieut.-Col. W. Lockwood Marsh, O.B.E.

The Council beg to thank most cordially the gentlemen who kindly read the papers and also those who consented to act as Chairmen.

Annual Dinner.

The first Annual Dinner that has been held for many years took place at the Connaught Rooms on November 17th when Lord Weir, the President, occupied the Chair, and 137 members and guests were present. The dinner was, it is felt, an unqualified success, which it is hoped to repeat next year. It may be mentioned that it involved no expense to the Society, there being in fact a small balance on the credit side after all expenses had been paid, the President having very kindly made himself responsible for some of the expenses.

Visit to the National Physical Laboratory.

Through the kindness of the Director of the National Physical Laboratory, a visit to the Aerodynamics' Department was arranged on January 26th, when about 50 members availed themselves of the opportunity of being shown over the experimental apparatus installed. It is hoped to arrange for a series of similar outings during the coming year as they appear to be likely to prove a popular feature.

Applications for Membership.

The Council have approved a scheme of examinations, and special qualifications to be accepted in lieu thereof, for admission to Associate Fellowship, and the detailed regulations for this and certain modifications in the regulations for the admission of Fellows are being laid before members for their concurrence at the Annual General Meeting.

Revision of Rules.

It has been felt for some time that certain modifications and additions to the Rules are advisable, and the opportunity has been taken of making the alterations rendered necessary by the new regulations referred to above to revise carefully all the Rules. The amendments proposed by the Council will therefore also be laid before the Annual General Meeting. It should perhaps be mentioned that it was felt desirable to introduce as little alteration as possible consistent with what the Council have felt to be the revision necessary.

Finance.

The Council beg to report that the past year's working has resulted in a deficit of £481 3s. 4d. as shown in the Income and Expenditure Accounts for the two periods of six months ending June 30th and December 31st, 1920. When compared with the deficit on a similar basis of £1,780 for the previous twelve months, it is felt that this result may be received with a certain satisfaction. The improved position is due in part to the increase in subscriptions and also to a considerable extent to the exercise of economies in the production of the Journal and to the cutting down of other printing expenses to the minimum possible. The Council are glad to be able to report that should conditions remain unchanged there is every reason to hope that during the year 1921 the receipts should be sufficient to cover the expenditure, particularly if a new advertisement contract for the Journal, which has been entered into as from January 1st, 1921, proves as advantageous as appears likely. It must, however, be borne in mind that so far as the Balance Sheet is concerned, there is a deficit of £1,542 19s. 11d. which has to be carried forward and which there seems little hope of wiping off for some years to come in the ordinary course of events. It may be mentioned in conclusion that a more detailed system of book-keeping has been introduced during the year as a result of which the ascertaining of the precise state of the finances at any time is made a matter of greater ease and certainty than before. This system has the advantage of rendering it more easy to locate causes of expense and consequently may be trusted to lead to more efficient and economical working. It is hoped also to exercise certain economies in the methods of auditing during the current year.

Publications.

Efforts have been made during the year to increase the interest of the Aeronautical Journal by printing more original articles as well as by getting together the best possible programme of lectures. An endeavour has been made also to keep members more in touch with the work of the Society both by improving the announcements at the beginning of the Journal, and by circulating to the aeronautical and daily Press weekly notices, which cover as far as possible both information as to arrangements and activities and the various decisions arrived at by the Council.

Honorary Officials.

The Council desire to express their most cordial thanks to Mr. B. Woodward, whose advice as Honorary Solicitor has been called upon on several occasions during the year, and to Mr. A. E. Turner, the Honorary Treasurer, who has given invaluable assistance in dealing with financial matters.

Auditors.

The Council desire to express their appreciation of the way in which the new firm of auditors, Messrs. Price, Waterhouse and Company, have carried out the two six-monthly audits, and also of Mr. F. C. Best's assistance in the preliminary work of preparing the figures for the audit. It is proposed during this year to rely upon the assistance of Mr. Best only for the preparation of a statement of the financial position at the end of the first six months, having an official audit at the end of the year.

Staff.

The Council feel that members are to be congratulated upon the keenness and efficiency of the office staff employed. This now numbers four—Secretary, Assistant Secretary, Book-keeping Clerk (Miss G. B. Silvester), and Junior Clerk (Miss F. Barwood).

Your Council wish to express their thanks to the Secretary, Colonel Lockwood Marsh, for the able and thorough manner in which he has carried out his duties in the past 12 months. The great improvement in the financial position, as compared with last year, is largely due to his efforts, and he has conducted all the business of the Society with unfailing tact and energy.

Miss O. St. Barbe, the Assistant Secretary, has a knowledge of the Society's work which has been invaluable during the first year of service of a new Secretary, and shows undiminished zeal and resource in furthering its aims; while the two assistants have proved themselves exceptionally hard-working and efficient.

HON. TREASURER'S STATEMENT IN PRESENTING THE ACCOUNTS FOR THE HALF-YEAR ENDED 31st DECEMBER, 1920.

The Income and Expenditure Account for the second half of last year shows a net deficiency of £203 18s. 2d., which, added to the deficiency of £277 5s. 2d. for the previous six months, makes a total deficiency for the year of £481 3s. 4d., as against the anticipated deficit of £850. The difference is accounted for by the fact that receipts for the second half-year had been estimated to be the same as for the first half of the year, while, in fact, they were £100 higher. The estimated decrease of £100 in expenditure was almost exactly realised, and it was only found necessary to write off £150 on account of arrears of subscriptions instead of the estimate of £400.

For the current year it seems not unreasonable to anticipate that the Society's income should almost, if not quite, balance the expenditure. There seems reason to hope for a somewhat increased subscription income; and the new advertisement contract for the Journal is expected to produce a substantial increase on the amount hitherto received from this source.

The Finance Committee has always hesitated to suggest inviting donations for the purpose of wiping out the accumulated deficiency of nearly £1,600 until such time as the Society's current finances appeared to be on a satisfactory basis. This time would now seem to have arrived, and it is accordingly suggested that in issuing their report for last year, the Council invite donations to a fund for this purpose.

ARTHUR E. TURNER.

February 15th, 1921.

AERIAL
(The Royal

INCOME AND EXPENDITURE ACCOUNT FOR THE

Dr.	£	s.	d.
To Office Rental, Lighting and Insurance	161	8	5
,, Salaries	535	18	3
,, Printing, Stationery, etc.	134	17	1
,, Postages and Messengers	43	12	8
,, Library Expenses	10	0	5
,, Office Expenses	32	13	5
,, Exhibitions and General Meetings	93	19	7
,, Journals, Pamphlets, etc.	173	9	8
,, Audit Fee	26	5	0
,, Subscriptions Written-off or Refunded	28	4	0
,, Reserve against Subscriptions Outstanding	149	1	6
	£1,389	10	0

BALANCE SHEET

		£	s.	d.	£	s.	d.
To Nominal Capital—							
Divided into 20 Shares of 1/- each and 999 Shares of £1 each		1,000	0	0			
,, Capital Issued and Called Up—							
11 Shares of 1/- each						11	0
,, Sundry Creditors					438	4	10
,, Subscriptions Received in Advance					152	5	4
,, Reserve Fund—							
Entrance Fees and Life Compositions of present Members, as at 30th June, 1920		2,421	0	0			
Receipts for six months to 31st Dec., 1920...		123	18	0			
Donations received		30	10	0			
		2,575	8	0			
Less Payments		12	12	0			
		2,562	16	0			
Deduct, Income and Expenditure Account— Deficiency at 30th June, 1920	£1,339 1 9						
Add Excess of Expenditure over Income for six months to 31st December, 1920 ...	203 18 2						
		1,542	19	11			
					1,019	16	1
					£1,610	17	3

We report to the Shareholders that we have examined the books of the
(We are not in a position to judge of the value put upon the outstanding sub
properly drawn up so as to exhibit a true and correct view of the state of the
given to us and as shown by the books of the Society.

3, Frederick's Place,
Old Jewry, E.C.2.
10th February, 1921.

SCIENCE, LTD.

Aeronautical Society).

SIX MONTHS ENDING 31st DECEMBER, 1920.

Cr.	£	s.	d.
By Subscriptions Apportioned for the Six Months	1,070	11	0
,, Sundry Subscriptions	62	14	8
,, Interest on War Loan and Deposit	20	4	8
,, Profit on Annual Dinner	32	1	6
,, Balance, being excess of expenditure over income	203	18	2
	£1,389	10	0

31st DECEMBER, 1920.

	£	s.	d.	£	s.	d.
By Office Furniture, Printed Books, Bindings, Stationery, Old Prints, etc., as at 30th June, 1920 ...				355	16	8
,, Stock of Journals, etc., in hands of Society and with Society's Printers, as estimated by the Secretary				50	0	0
,, Stock of Stationery				13	0	0
,, Sundry Debtors, including Subscriptions Owing ...				298	16	6
,, Investments at Cost—						
£500 5% War Loan (Inscribed Stock, 1929/47)	475	13	6			
£100 5% War Bond	100	0	0			
				575	13	6
,, Cash at Bank and on Deposit	316	10	2			
,, Cash in hand	1	0	5			
				317	10	7
				£1,610	17	3

Society and have obtained all the information and explanations we have required. scriptions.) Subject to this remark, we are of opinion that such Balance Sheet is Society's affairs according to the best of our information and the explanations

PRICE, WATERHOUSE & CO.

PROCEEDINGS.

SIXTH MEETING, 56th SESSION.

The Sixth Meeting of the Fifty-Sixth Session was held in the Hall of the Royal Society of Arts, London, on Thursday, December 16th, 1920, Lieut.-Col. H. T. Tizard presiding.

The CHAIRMAN said the Lecturers, Mr. Ricardo and Mr. Rowledge, were so well known to the members that it would be a waste of time to enumerate their virtues. He would ask Mr. Ricardo to read his Paper.

Mr. H. R. RICARDO then delivered the following lecture:—

SOME POSSIBLE LINES OF DEVELOPMENT IN AIRCRAFT ENGINES.

In the following paper the writer's aim is to indicate certain possible lines of development and research which his own investigations and preliminary experiments have shown to be at least worthy of serious consideration.

If we review the present state of the art we find the position to be substantially as follows:—From a thermodynamic point of view the performance of the modern aero engine has approached so nearly to the ideal obtainable from the cycle on which it operates that there is little scope for improvement. Thermal efficiency or fuel consumption is now the all-important factor, but since the best modern aero engines are actually developing a thermal efficiency within 4 or 5 per cent. of the highest obtainable from the cycle on which they operate, it is evident that

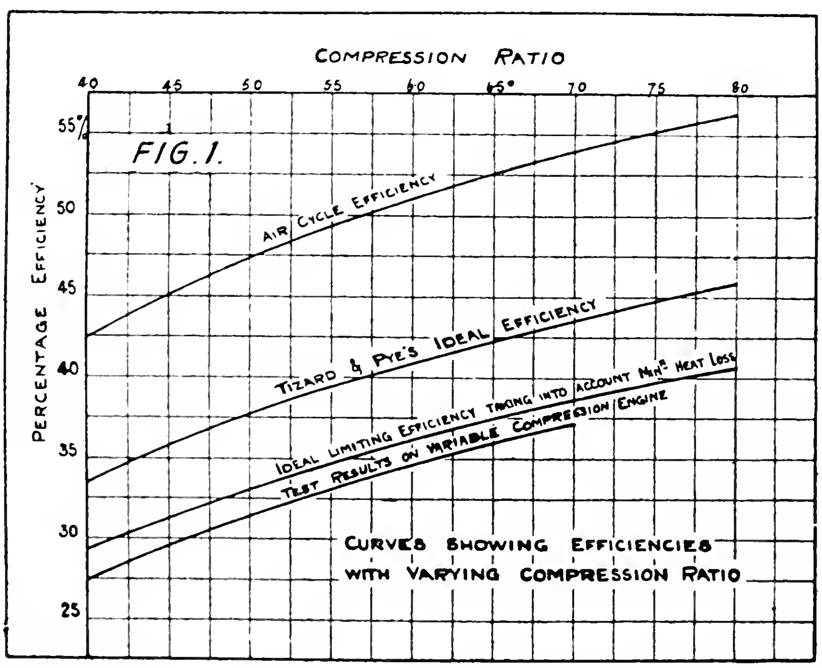


FIG. 1.

to gain any further improvement it will be necessary either to depart from, or at least to take considerable liberties with, the accepted cycle, or to modify the composition of the fuel, or both.

The cycle on which all present-day aero engines operate is one in which an explosive mixture of fuel and air is drawn into the cylinder compressed to the highest pressure permissible without detonation and ultimate pre-ignition, then ignited at constant volume and expanded until it occupies the same volume as before compression, after which it is released and the cycle is repeated. The theoretical efficiency of this cycle is given by the formula $E = 1 - (1/r)^{\gamma - 1}$

This is known as the air standard efficiency; it assumes that the specific heat is constant at all temperatures, that there is no loss of heat and that there is no dissociation. According to this formula the efficiency is dependent upon r, the

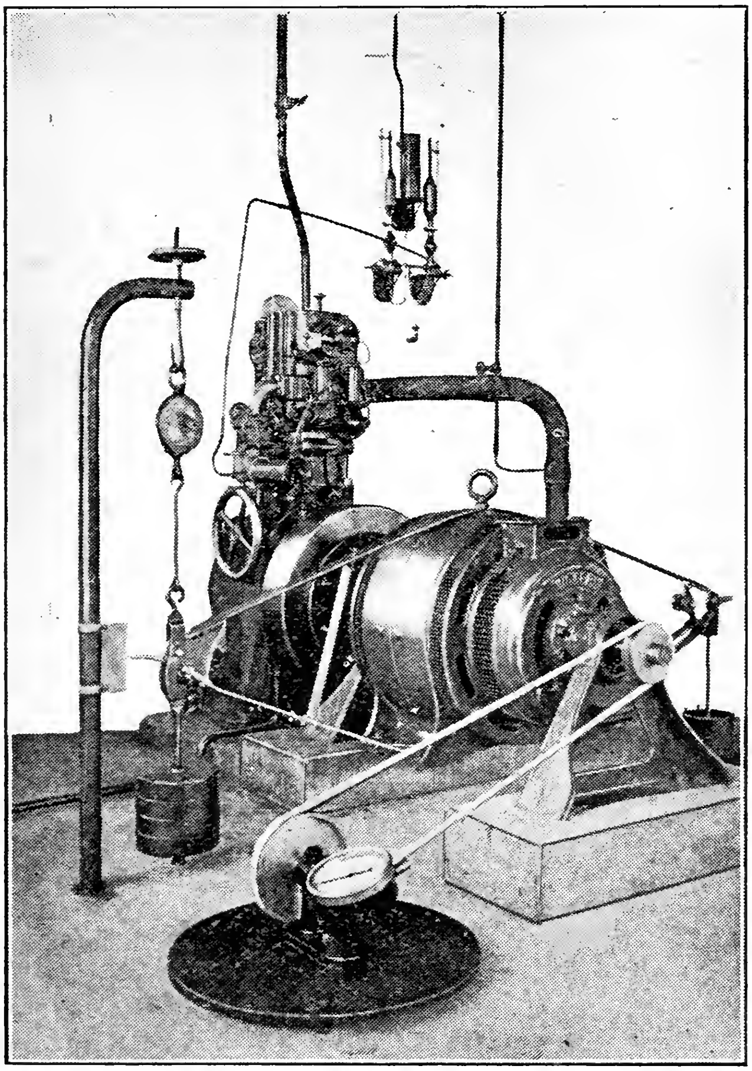


FIG. 2.

expansion ratio. In the ordinary cycle r is also the compression ratio, since compression and expansion happen to be equal, but it must be remembered that it is the expansion and not the compression ratio which governs the efficiency, and that the two need not necessarily be equal.

The most recent investigations on the properties of the working fluid carried out by Mr. Tizard and Mr. Pye and corroborated by the writer's experimental results, show that when due allowance has been made for the losses due to change of specific heat and to dissociation at the temperatures which actually obtain in the cylinder, the true limiting thermal efficiency becomes approximately $E = 1 - (1/r)^{0.295}$. This formula takes no account of the losses due to the direct passage of heat to the cylinder walls during combustion and expansion. It is

clearly impossible to arrive at a really universal formula which will take this into account, since the proportion of heat lost must depend upon the form of the combustion chamber, the speed, and, in fact, on the individuality of each engine. In the most perfect case of an engine having a compact and symmetrical combustion chamber and running at a high speed, so that the direct heat loss during combustion and expansion is reduced to the absolute minimum, the highest attainable indicated thermal efficiency is given pretty accurately by the formula $E = 1 - (1/r)^{0.25}$. This allows for the minimum possible heat loss to the jacket walls and may be regarded as the absolute limiting thermal efficiency obtainable under the best possible conditions, assuming :—

(1) Perfect carburation and distribution.

(2) That the compression and expansion ratios are equal.

(3) That the mixture is homogeneous and of the most economical strength.

FIG. 3.

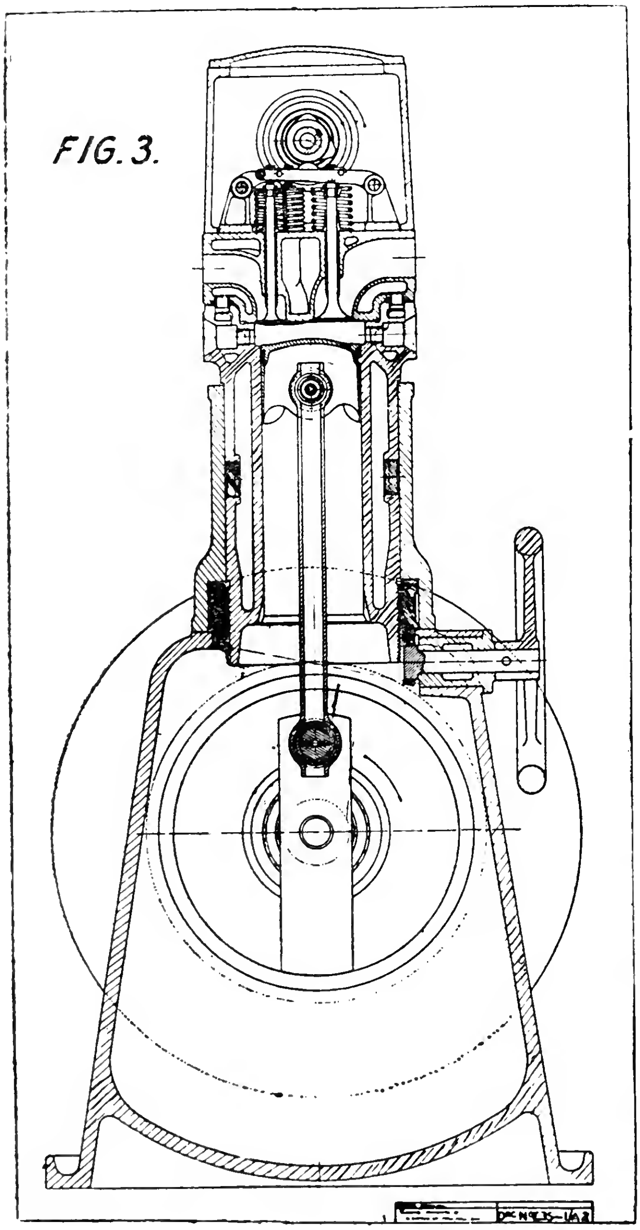
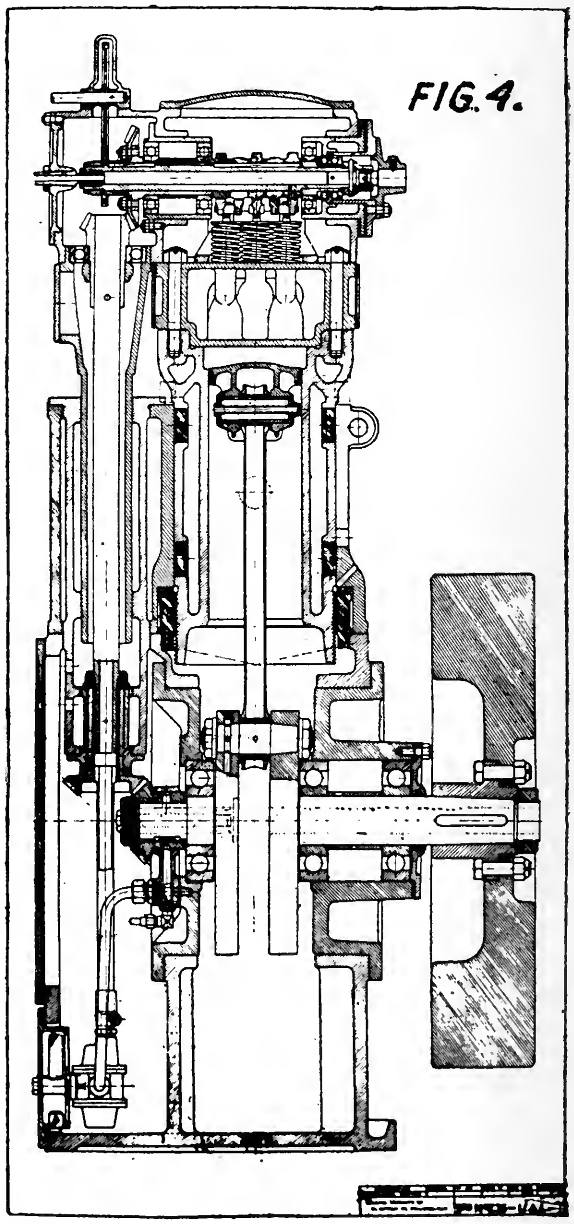


FIG. 4.



The following table (Table I.) and the curves shown in Fig. 1 gives in column (1) the air-cycle efficiency for a range of compression ratios from 4 : 1 to 8 : 1 column (2), Tizard and Pye's ideal efficiency, taking into account losses due to change in specific heat at high temperatures and to dissociation, column (3) the highest attainable indicated thermal efficiency assuming that the combustion

chamber is designed to allow of the minimum possible heat loss, that the cylinder is of comparatively large capacity and that the revolutions are not less than 1,500 r.p.m. In column (4) are given the actual indicated thermal efficiencies as obtained in a special variable compression engine designed by the writer for research purposes, and in which every known artifice for obtaining the highest possible efficiency and power output has been employed. A photograph and sectional drawings of this engine are shown in Figs. 2, 3 and 4.

TABLE I.

Expansion ratio.	Col. 1. $E = 1 - (1/r)^{0.4}$	Col. 2. $E = 1 - (1/r)^{0.295}$	Col. 3. $E = 1 - (1/r)^{0.25}$	Col. 4. Observed results variable compression engine.
4.0	0.4256	0.336	0.296	0.277
4.5	0.4521	0.359	0.314	0.297
5.0	0.4747	0.378	0.332	0.316
5.5	0.4944	0.396	0.348	0.332
6.0	0.5116	0.411	0.361	0.346
6.5	0.5270	0.424	0.375	0.360
7.0	0.5398	0.437	0.386	0.372
7.5	0.5534	0.449	0.396	0.383
8.0	0.5647	0.460	0.406	—

The difference between columns 3 and 4 indicates the scope left for improvement—it is very narrow.

So long as the recognised cycle is adhered to, in its entirety, the importance of raising the compression and therefore the expansion is obvious. Now when working with all fuels belonging to the general group known as petrol the compression pressure which can be employed is limited by the tendency of the fuel to detonate and ultimately to pre-ignite.

The explanation of the phenomena of detonation appears to be as follows:—

When the mixture is ignited from any one point, the flame at first spreads by the normal process of flame propagation aided by turbulence and in doing so compresses before it the unburnt portion of the charge; unless this latter can get rid of its heat with sufficient rapidity, it is liable to be compressed to a temperature exceeding its self-ignition temperature, with the result that it ignites spontaneously throughout its whole bulk and an explosion wave is set up which strikes the walls of the cylinder with a hammer-like blow, giving rise to the familiar noise known as "pinking." This explosion wave further compresses the portion of the charge first ignited, thus still further raising its temperature, and with it the temperature of the igniter points or any other partially insulated object in the neighbourhood from which ignition first started, to so high a temperature as ultimately to cause pre-ignition and loss of power. Pre-ignition, which is the ultimate limiting factor controlling the compression, never occurs under normal conditions with petrol, except as a result of persistent detonation. If detonation be prevented, a much higher compression can at once be used without any risk of pre-ignition, and a very decided gain both in power and efficiency obtained thereby.

There can be little doubt but that detonation depends primarily upon the normal rate of burning of the fuel, and this in turn depends upon the pressure, and, to a less extent, upon the temperature at the time of ignition. If means be adopted either for slowing down the normal rate of burning or raising the self-ignition temperature of the fuel, or both, detonation can be kept in control and a much higher compression ratio can be used. Either or both of these methods are available. With the exception of ether, acetylene and hydrogen, fuels composed of light paraffin fractions have been proved to be the worst offenders as regards detonation—they are chain compounds and therefore chemically unstable, their ignition point is low, and their normal rate of burning very rapid. On the other

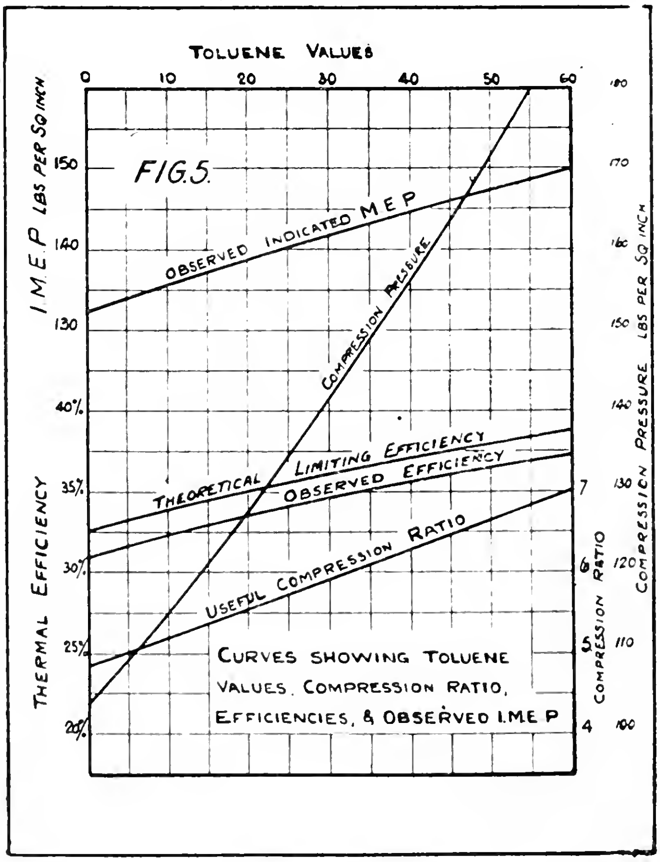
hand, fuels belonging to the aromatic group, such as benzene, toluene and xylene are ring compounds of greater chemical stability and high ignition temperature, they cannot be made to detonate even with compression ratios as high as 7.5 : 1.

It has been known for a long time that by adding benzol or benzene to paraffin petrols the tendency to detonate could be greatly reduced, but recent experiments at the writer's laboratory have shown that of these three members of the aromatic group, benzene is the least effective and toluene the most, while xylene occupies a position midway between the two. On account of their relatively low heat value per lb. it is naturally desirable to employ as small a proportion of aromatics as possible. Of the three aromatics mentioned, benzol has also the highest specific gravity and the lowest heat value per lb. It is therefore from every point of view the least efficient of the three.

Experiments on the variable compression engine have shown that the compression pressure can be raised in direct proportion to the aromatic content of the fuel. A light petrol freed from aromatics and consisting mainly of fractions of the paraffin series, but conforming in every respect to the Air Ministry's specification for aircraft spirit, detonates under normal conditions as to temperature, etc., and with the most efficient mixture strength and ignition timing at a compression ratio of 4.85 : 1 (the degree of compression at which detonation starts being very sharply defined). By adding 20 per cent. of toluene the compression can be raised from 4.85 : 1 to 5.57 : 1, the gain in efficiency on actual test is found to be from 31.1 per cent. to 33.5 per cent., and in mean effective pressure from 131.8lbs. per sq. inch to 140lbs. per sq. inch. Now the addition of 20 per cent. toluene adds less than 2 per cent. to the weight of the fuel per unit of heat and permits of an increase in efficiency of 7 per cent. The net gain is therefore very considerable.

Finding toluene the most efficient medium for preventing detonation, it was decided to express the tendency of fuels to detonate in terms of their toluene value.

Starting with a light paraffin petrol, freed from aromatics, the relation between toluene value and the highest compression ratio which could usefully be employed was found to be as shown in the following table and the curves in Fig. 5 :—



Toluene value.	Compression ratio.	Ind. mean pressure as found by experiment.	Ind. thermal efficiency as found by experiment.	Limiting Ind. thermal efficiency.
0	4.85 : 1	132.5	·311	·327
10	5·20 : 1	135·4	·323	·338
20	5·57 : 1	138.7	·335	·350
30	5·94 : 1	142.0	·347	·361
40	6.32 : 1	144.9	·355	·371
50	6.67 : 1	147.5	·365	·380
60	7.05 : 1	150.0	·373	·388

Later investigations showed that toluene was not the most efficient dope, and that, in fact, it could not compare with alcohol, though this fuel is not likely to be of much value for aircraft on account of its low heat value per lb.

The following table gives the toluene values of a number of different fuels. For permission to publish this table the writer is indebted to The Asiatic Petroleum Co., Ltd., for whom these and other investigations were carried out.

TOLUENE VALUE.

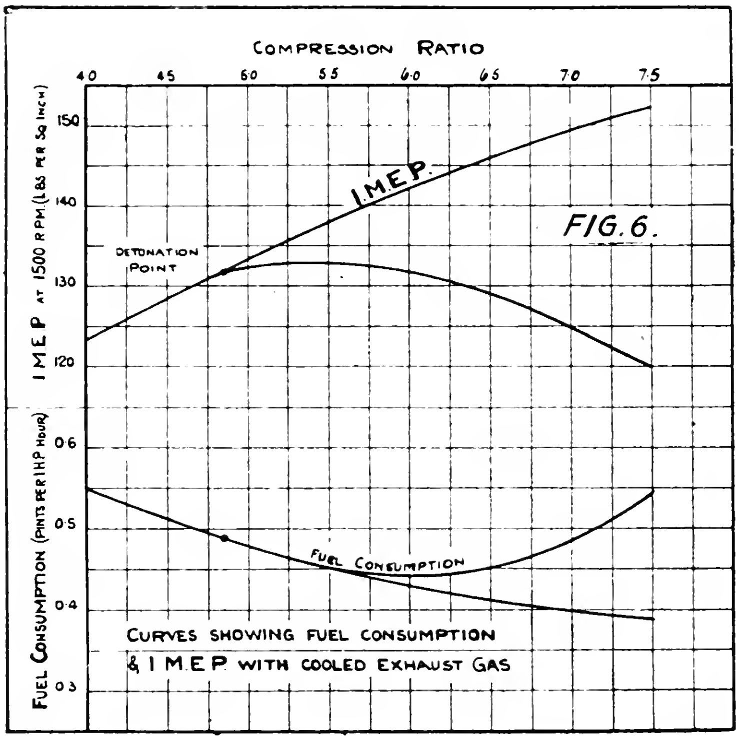
Toluene	+ 100
Benzene	+ 66
Xylene	+ 83
Ethyl-Alcohol, 99 per cent.	+ 166
Acetone	+ 75
Cyclohexane	+ 30
Carbon Bisulphide	+ 10
Methyl Mercaptan	+ 5 to 10
Ether	— 60

From this table it will be seen that the fuel known as hectar and consisting of 50 per cent. benzene and 50 per cent. cyclohexane, which the Americans have found so successful, therefore has a toluene value of 48, and could be used with a compression ratio of 6.6 : 1.

Before proceeding further it would be well to emphasise that of all the known volatile hydro-carbon fuels the total internal energy (taking into account the heat of combustion on the one hand and the change in specific volume on the other) is substantially the same, that is to say, when completely evaporated and used at the same compression ratio, all fuels, irrespective of their heating value, will give the same thermal efficiency and the same power to within about 2 per cent. The only exception is alcohol and the other members of its group; these, under normal conditions, give a slightly higher power because the increase of specific volume after combustion is very considerable, and also in practice owing to their higher latent heat they are seldom completely evaporated, with the result that a considerable amount of evaporation takes place in the cylinder during the suction stroke, thus both increasing the weight of charge and reducing the compression temperature.

Popular theories that benzol or mixtures of benzol and petrol give higher power at the same compression than pure petrol, owe their origin to the fact that most engines have already too high a compression for efficient use with pure petrol, with the result that a late ignition setting and often an over-rich mixture also must be used. The addition of benzol in such a case permits of the use of full ignition advance and the most efficient mixture strength, and so gives rise to this very prevalent impression. Actually the total internal energy of, and therefore the power output available from benzol, is very slightly less than petrol.

Apart from varying the composition of the fuel, which is not always practicable, a somewhat similar increase in compression and therefore in efficiency can be obtained by the addition of inert gases which serve merely to delay the normal rate of burning. Experiments with pure aromatic-free petrol of toluene value 0 showed that the safe compression ratio could be raised from 4.85 to 1 up to 7.5 : 1 by the addition of cooled exhaust gas. Fig. 6 shows the relation between mean

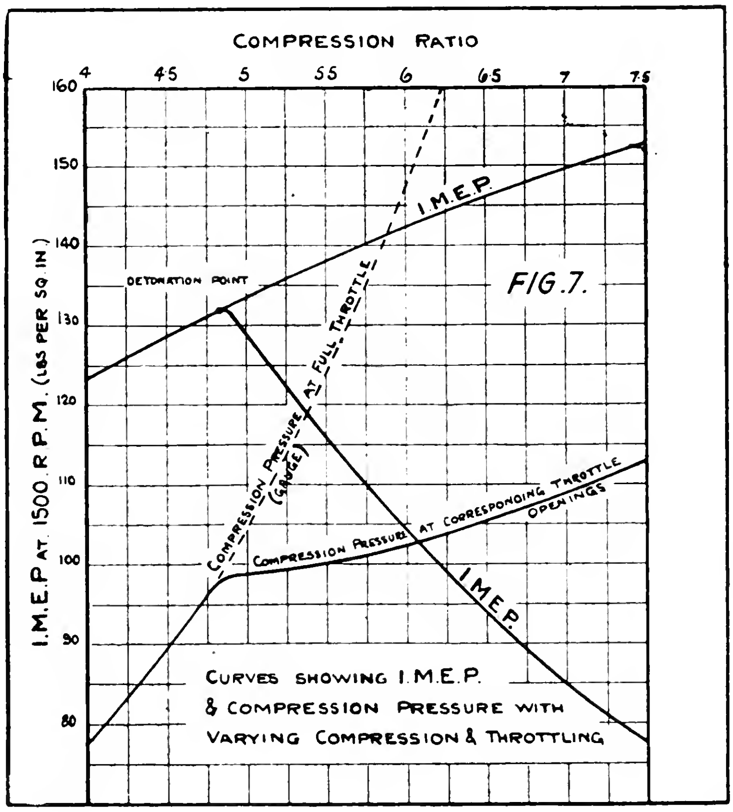


pressure, thermal efficiency and compression ratio, when just sufficient exhaust gas was admitted in each case to check detonation. In dotted lines are shown, by way of comparison, the mean effective pressure and efficiency obtained with a fuel of high toluene value and of the same total internal energy. The divergence between the two mean pressure curves indicates approximately the proportion of inert gas added. It will be observed that the compression ratio can be raised at once from 4.85 : 1 to over 6 : 1 without any reduction in power whatever, and with a very substantial gain in efficiency, thus it is possible to improve the economy of an engine by as much as 6 per cent. without affecting its horse-power one way or the other, by the mere addition of exhaust gas, costing nothing, and adding nothing to the weight of the engine.

To appreciate the possibilities of the use of exhaust gas in this manner, let us suppose that we have a fuel of toluene value 0. With such a fuel the highest compression ratio we can use if the engine is to be capable of running "full out" at ground level, and with an economical setting, is only 4.85 : 1, corresponding to a limiting thermal efficiency of 32.7 per cent. By the addition of cooled exhaust gas a compression ratio of say 7 : 1 giving a limiting thermal efficiency of 38.6 per cent. could be used and still permit of the engine being run full out on the ground with perfect safety, and developing even at ground level very nearly the same power as the lower compression engine.

As the machine ascended the quantity of exhaust gas would be reduced until at about 12,000 feet it could be cut off altogether. It will be seen that, in this manner, not only can a high compression engine be made to operate safely on the ground with any fuel, but that the control of exhaust gas can be made to afford a very efficient altitude compensator.

By way of comparison, tests were run with varying compressions and with a fuel of toluene value o in order to ascertain the relation between mean pressure, compression pressure and compression ratio when detonation is prevented by throttling. The results obtained are shown in Fig. 7 and require no particular



explanation. It is interesting to note, however, that detonation became apparent at very nearly the same compression pressure in all cases. By way of comparison it will be noted that with this fuel the throttled engine with 7 : 1 compression ratio can develop only 57 per cent. of its full power on the ground while the exhaust controlled engine can develop 84 per cent.

Safety Fuels.

A good deal of interest has been shown lately in the question of employing fuels of high flashpoint to avoid fire risks. So far as the writer is aware, kerosene only has as yet been seriously considered. There are two possible methods of dealing with this fuel, (1) by vaporising it and so using it in a normal type of engine, (2) by injecting it into the cylinder as a liquid, either during the suction stroke or at the end of compression.

With regard to the first method, commercial kerosene consists almost entirely of heavy fractions of the paraffin series. These are all chain compounds, and their chemical stability decreases with increase in molecular weight. From the point of view of detonation, therefore, kerosene is one of the most troublesome fuels in existence. Further, in order to vaporise a reasonable proportion of it, it is necessary to raise its initial temperature to certainly not less than 60°C. This means a reduction in the weight of charge of at least 20 per cent. as compared with petrol, and a corresponding reduction in mean pressure. Further, owing to its chemical instability on the one hand and the high compression temperature resulting from pre-heating, the limiting compression is reduced to about 4.2 : 1 corresponding to a limiting thermal efficiency of only 30.2 per cent. and a limiting indicated mean pressure of only about 115lbs. per sq. inch or say 100lbs. per sq. inch brake mean pressure. Again, no means have yet been discovered of preventing the heavier fractions condensing on the cylinder walls and passing down

into the crank-case, where they soon prove destructive to the bearings, etc. So serious has this trouble proved in the case of stationary kerosene engines that so far the only kerosene engines of normal type which have given consistently satisfactory results over long periods are those in which the working parts are open and each bearing is lubricated individually. Although detonation can be kept in check and a comparatively high compression ratio employed with the help of the addition of exhaust gas, yet the low-power output, the condensation trouble, and the low efficiency are such serious drawbacks as, in the writer's opinion, to put kerosene out of court as a fuel for existing types of aero-engines. The alternative method of injecting the fuel is not much more hopeful so long as it is applied to the existing type of engine. If the fuel is injected on the suction stroke one avoids the loss due to pre-heating, and can therefore use a higher compression and obtain considerably higher power, but the condensation trouble becomes more serious than ever, while the problem of measuring and pumping small quantities of fuel and maintaining correct proportions between the fuel and air at all loads and speeds is no easy one.

Lastly, if the fuel be admitted at the end of compression and ignited on entry by means of a hot plate or other igniter, the very formidable difficulty of so pulverising and distributing the fuel that each particle can find at once the necessary air for complete combustion has got to be tackled; it is one which is very familiar to the Author from bitter experience with Diesel and semi-Diesel engines.

There is, however, another way of dealing with the high flashpoint fuel problem which, in the writer's opinion, is the most hopeful at the moment. Many natural kerosenes contain a considerable proportion of heavy aromatic hydrocarbons having the same characteristics as regards flashpoint as the kerosene of which they form a part. These aromatics burn with a smoky flame, and are therefore very objectionable when the fuel is used as an illuminant. Recently steps have been taken to isolate and remove these heavy aromatics, and at the present time they are being removed at the rate of several thousand tons per month. Their use as a safety fuel for aircraft engines is worthy of careful consideration. Owing to their almost complete immunity from detonation they can be used with a very high compression ratio, even after pre-heating in a vaporiser. Experiments made with these aromatic extracts show that with an inlet temperature of 60°C. it is still possible to use a compression ratio as high as 6 : 1, and even 6.5 : 1, with the result that the efficiency is very high and the power output equal to or very nearly equal to that obtained with ordinary petrol of low Toluene value. Direct comparative tests carried out with paraffin and samples of these aromatic extracts gave the following results:—Kerosene sp. gr., 0.812; I.M.E.P., 111.0; Fuel pt. per 1 H.P. hr., 0.595; Aromatic Extracts sp. gr., 0.884; I.M.E.P., 125.5; Fuel pt. per 1 H.P. hr., 0.42. In both cases exactly the same vaporiser temperature was used, the only difference being in the compression ratio employed. The results obtained are, in the writer's opinion, sufficiently encouraging to justify further investigation. The difficulty of condensation still remains, but this appears to be less serious than with kerosene since the freedom from any tendency to detonate permits of more pre-heating, while it is open to question whether the heavy aromatic condensate is as destructive to lubrication as the paraffin.

Influence of Mixture Strength.

In the earlier part of this Paper the writer has shown that because of the losses to dissociation, change of specific heat and direct heat losses, the limiting efficiency obtainable under the best conceivable conditions is only about 70 per cent. of the air cycle. Now each of these sources of loss is a direct function of the maximum temperature, which in turn is dependent upon the mixture strength. When the mixture is so proportioned that the whole of the available oxygen is just combined, the maximum temperature rises to approximately 2,500°C., and the

mixture strength is then approximately 47 ft. lbs. per cub. inch. As the mixture is weakened the maximum temperature is of course reduced, at first only very slightly, but so long as a homogeneous mixture is employed it is not possible to reduce the mixture to below about 40 ft. lbs. per cub. inch. without serious loss of efficiency due to incomplete combustion, owing to the limited range of burning of all volatile hydrocarbon fuels. The writer has carried out on behalf of the Asiatic Petroleum Company, Limited, a very large number of tests on about 40 different fuels in order to ascertain the relation between mixture strength, power and economy. Except for insignificant variations, the characteristic efficiency and power obtained by gradually weakening the mixture is the same for all fuels and at all compressions, excepting alcohol, which on account of its greater latent heat and its large increase in specific volume gives increasing power as the mixture is enriched for a long period after the point of complete combustion has been passed.

The curve (Fig. 8) shows the relation between thermal efficiency and mixture

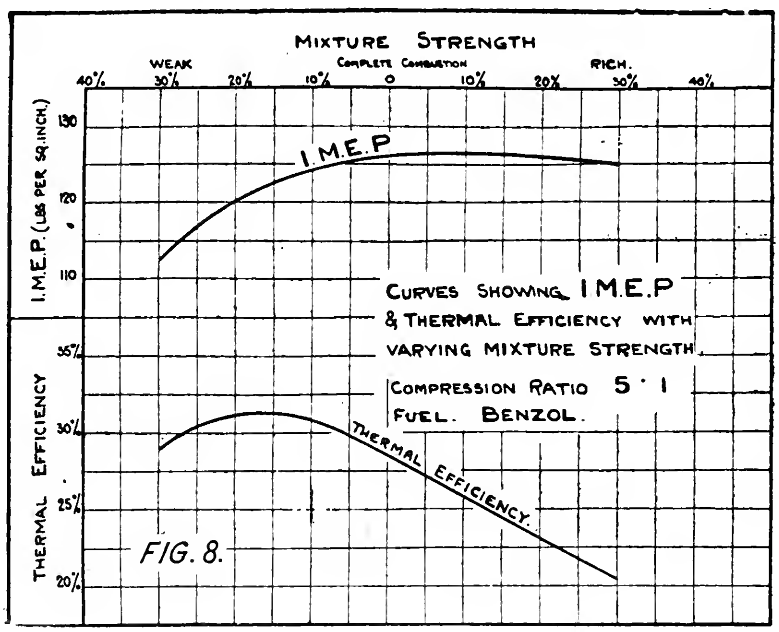
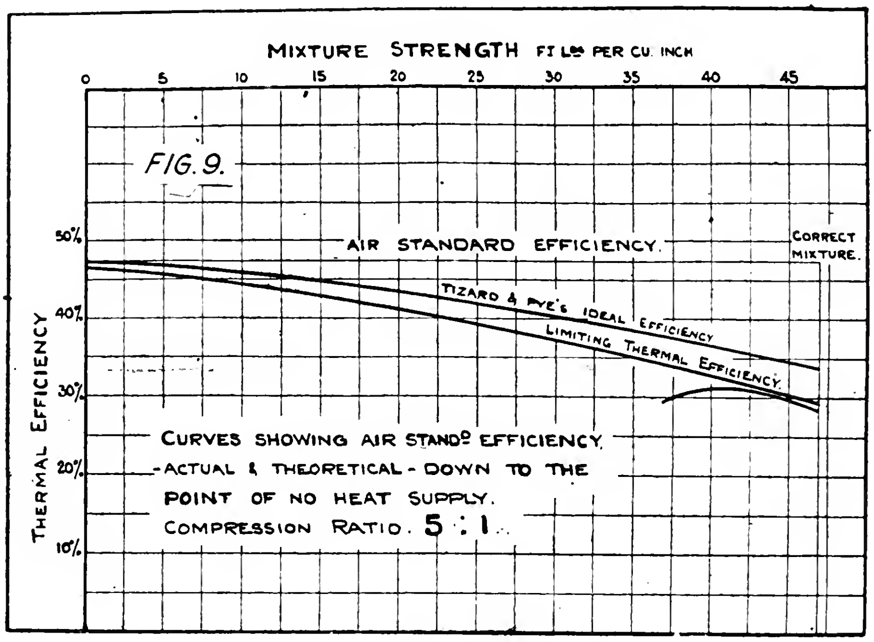


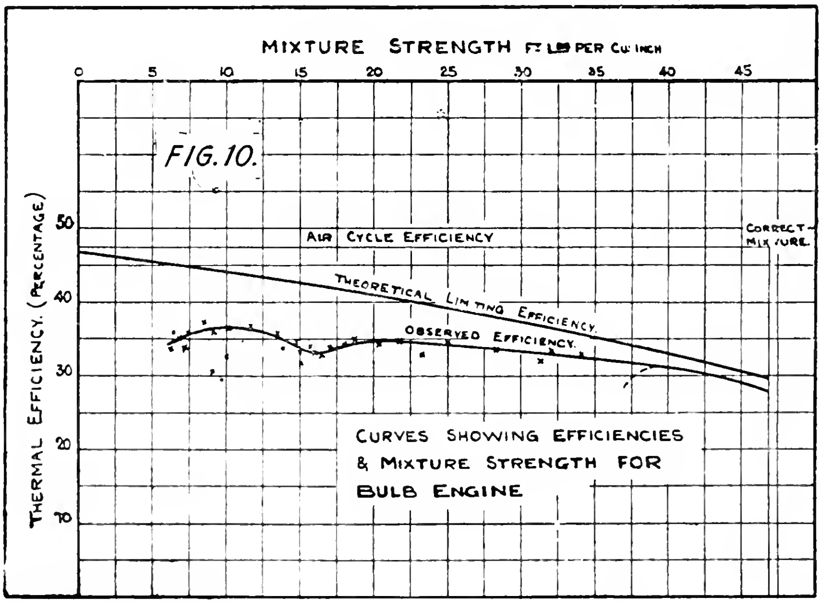
FIG. 8.

strength expressed in terms of mean pressure. The example shown is taken with benzol at a compression ratio of 6 : 1 and, with but infinitesimal variations, it may be taken as applying to any fuel except alcohol. It will be observed that maximum efficiency is obtained when the mixture strength is such that the mean effective pressure is about 3 per cent. below the maximum. Any further weakening of the mixture results merely in loss of efficiency due to incomplete combustion. Now were it possible to control the power output by mixture strength alone, and still obtain complete combustion, it is clear that the maximum temperature would then be proportional to the load and would diminish as the load is reduced. As the temperature diminished so also would the losses due to dissociation, change of specific heat, and direct heat loss diminish until, at the point of no load and therefore of no heat supply, they would disappear entirely and the limiting efficiency would be virtually coincident with the air cycle. The accompanying curve (Fig. 9) shows how, under these conditions, the limiting thermal efficiency would vary with the load. In this diagram the horizontal line denotes the air-cycle efficiency which, since it takes no account of heat losses, etc., is constant for all loads, the sloping line denotes the theoretical limiting efficiency over the range from no load to full load, the third line represents the limiting efficiency with minimum heat losses, and the fourth the actual test results obtained over the range of mixture strength available with a homogeneous charge. While it is not possible to weaken the mixture strength so long as the charge is homogeneous, it is possible to do so

by means of stratification, that is to say, by supplying the cylinder with a relatively small charge of combustible mixture and admitting separately a large charge of air, keeping the two separate until after ignition. To do this it is necessary to reconcile two conflicting conditions—the two portions of the charge must be prevented from mixing till after ignition, and at the same time there must be

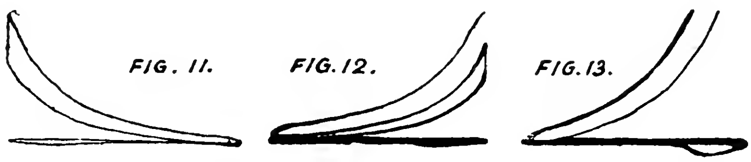


sufficient turbulence in the combustible charge to ensure rapid combustion. These two conditions are not irreconcilable, and the writer has succeeded experimentally on two engines in obtaining the whole range from dead light to full load by controlling the fuel alone. Under these circumstances not only is the efficiency on reduced loads far higher than could be obtained by any other means, but the heat loss is so low that a water-cooled engine can be run at reduced loads for any length of time without cooling water.



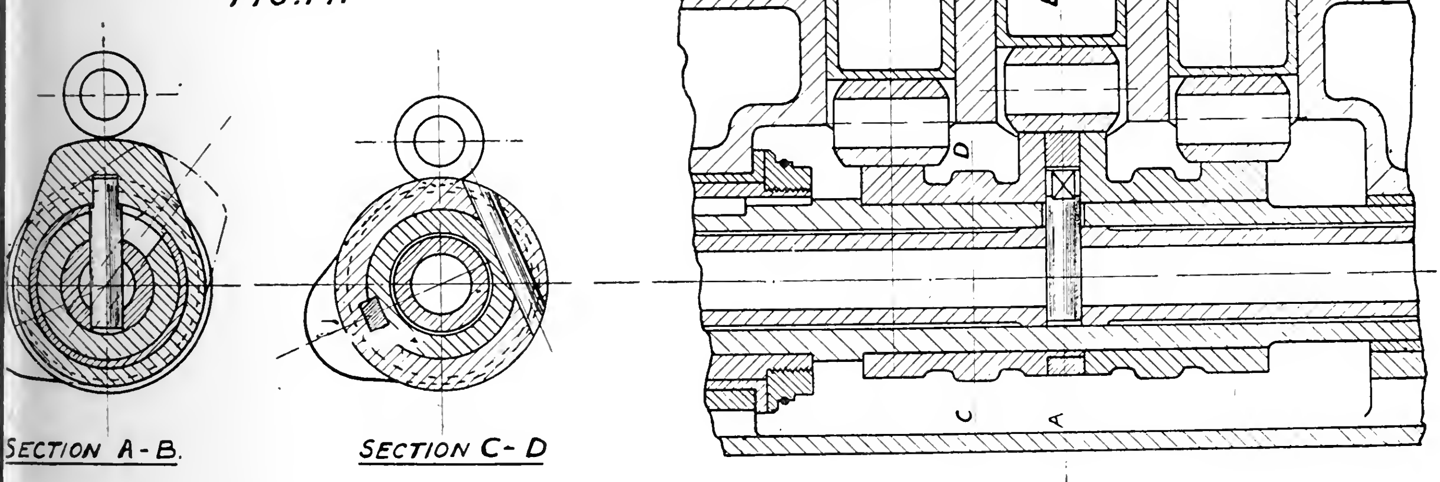
The accompanying curve (Fig. 10) shows the efficiency actually obtained in one experimental engine with a compression ratio of only 5 : 1. It will be observed that it rises to no less than 37 per cent. at about one third full load corresponding to a fuel consumption of just under 0.36 pint of benzol per indicated horse-power hour. It will be seen that the curve of efficiency actually obtained follows the

theoretical curve with a reasonable degree of approximation. In Figs. 11-14 are shown some typical indicator diagrams taken from one of the two engines with a Hopkinson optical indicator. It should be noted that when working on this system distribution troubles disappear. In any ordinary multi-cylinder engine it is necessary so to proportion the mixture that the weakest cylinder receives a charge of a



certain minimum strength to ensure regular running; this means that other cylinders are receiving a slightly richer charge than is absolutely necessary and their efficiency is therefore reduced. On the other hand, when working with a stratified charge, the power output of each cylinder is dependent solely upon the quantity of fuel admitted to it, so that any cylinder which receives a richer mixture than others will develop correspondingly more power, and the economy will always be at a maximum, that is assuming, of course, that the mixture strength is at all times below that required to consume the whole of the oxygen. Again, from the point of view of altitude compensation nothing could be simpler, for (so long as the oxygen in the cylinder is not all consumed) constant power can be maintained

FIG. 14.



SECTIONS THROUGH CAM BLOCK

over any reasonable range of density by merely supplying a constant fuel feed, *e.g.*, by gravity, or if a carburettor is used in its crudest form, the variation in power with altitude will correspond with the natural characteristic of the carburettor and will therefore vary as the square root of the density.

With a view to gaining further practical experience with this system, one of the two gas engines supplying power to the writer's laboratory was, about nine months ago, converted to run with stratified charge and control on the fuel alone. Since that date it has run continuously under violently fluctuating loads and has developed no trouble of any kind. It is running in parallel with another engine identical in every respect but working on the ordinary cycle. In the case of the latter engine it is necessary to remove the cylinder head every two months for decarbonising and grinding in the exhaust valve, while the cylinder of the engine working on the stratified charge has only been opened once, when it was found to be practically clean, while the exhaust valve appeared to keep almost as cool as the

inlet valve in the other engine. As regards governing and regularity of running there is nothing to choose between the two engines, each of which can develop a maximum of 24 b.h.p. at 750 r.p.m.

Although the above experiments suggest that the system has been developed to a practical stage, the writer feels that this is hardly yet the case and that considerably more research is required before it can be considered wholly satisfactory.

In the writer's opinion the potentialities of working with a stratified charge cannot be over-estimated. It opens up the possibility of obtaining far higher efficiencies than are obtainable by any other known means, and what is perhaps equally important, it reduces the temperature of the cycle and with it all the troubles due to high temperatures which directly or indirectly are the root cause of most mechanical failures. Since the rate of heat flow to the cylinder walls varies roughly as the cube of the temperature, and the power output practically directly as the temperature, it follows that quite a small reduction in power will reduce the heat losses to an extent that must render air-cooling quite a simple problem.

The possibilities of working with a short compression and long expansion stroke deserve careful consideration. In effect this can be accomplished by the simple expedient of closing the inlet valve late, so that compression does not start until well up the compression stroke; this method has both direct and indirect advantages. The direct advantages are that while the compression pressure is controlled by the nature of the fuel, the expansion ratio can be extended to any degree and very high efficiencies can be obtained, though, of course, at the expense of the power developed per unit of cylinder volume.

For example, suppose that a fuel of Toluene value *O* is used, then while the compression ratio is limited to 4.85 : 1 on the ground, the expansion ratio may be say 8 : 1. The limiting efficiency for 4.85 : 1 expansion is 32.7 per cent., and for 8 : 1, 40.6 per cent. The power output under these conditions will therefore be $4.85/8 = 60$ per cent. of that obtainable with an 8 : 1 compression, assuming that such a compression could be employed, or 73 per cent. of that obtainable if both compression and expansion ratio were 4.85 : 1. By varying the time of closing of the inlet valve the compression could be increased as the machine ascended, until at about 15,000 feet the full compression could be used and full power developed; thus the indicated thermal efficiency could be maintained at a maximum, and the power nearly constant over this range of altitude.

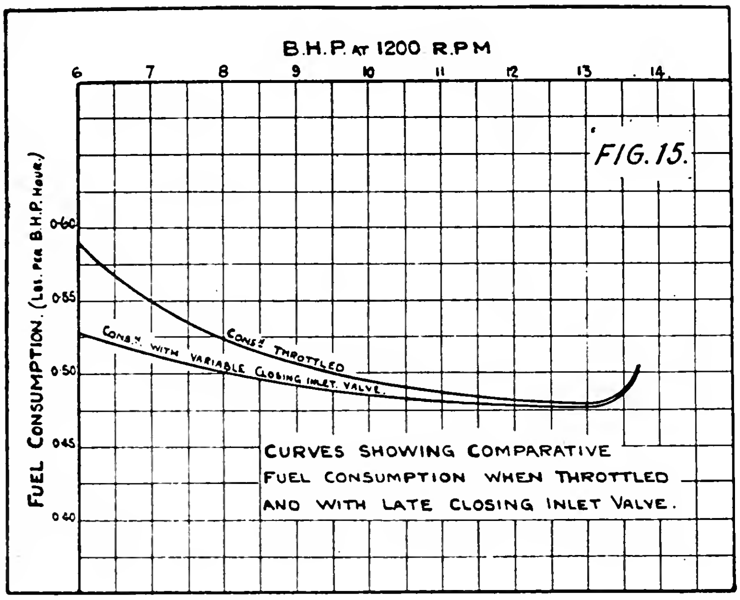
The indirect advantages are :—

(1) That with such a valve setting the engine has a rising torque curve which is a desirable characteristic.

(2) In the event of one cylinder dropping out and the speed falling in consequence, the compression in the remaining cylinders is reduced, and the shocks due to the irregular turning moment are also reduced. When controlled by throttling, the reverse is the case; if one cylinder drops out the others, owing to the drop in speed, take in a heavier charge, resulting in severe shocks and increased liability to detonation and pre-ignition.

(3) When working with a late closing inlet valve the whole charge enters the cylinder and a portion is rejected. The rejected portion, which returns to the manifold, has picked up a considerable amount of heat from the inlet valves, cylinder walls and residual exhaust gases, some of which heat it imparts to the inlet manifold with the result that, as the load is reduced, so is the temperature of the manifold increased, which is a desirable characteristic.

Some years ago the writer carried out a series of experiments with a patent variable inlet cam (shown in Fig. 15) fitted to a small experimental engine having an expansion ratio of 5.95 : 1. A number of very careful comparative power and consumption tests were made, the power output of the engine being controlled in the one case by varying the time of closing of the inlet valve, and in the other by using a normal valve setting and throttling the charge. The results obtained in



these experiments are shown in Fig. 16, from which it will be observed that the gain in efficiency in the former case, though perhaps not so large, is none the less quite appreciable. It should be noted that in these experiments the same expansion ratio was used in both cases, so that the advantage due to prolonged expansion was not obtained, and the gain in economy recorded is that due to indirect advantages alone.

In aircraft engines when one is working over a large range of atmospheric density the question always arises—at what density the engine shall be designed to give its best performance or at least to develop its full power. Until comparatively recently all engines were so designed that they could develop their full power

FIG. 16.

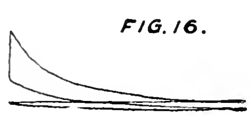
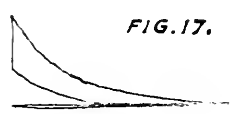


FIG. 17.



at ground level, without pre-ignition, without overheating, and without over-stressing the parts. During the war, however, it became evident that this was unnecessary and undesirable, and manufacturers were urged to design their engines on the assumption that they would not be opened full out below 10,000 feet. So far as the writer is aware, no manufacturers actually produced such an engine. It is, however, interesting to consider what might be done in this direction. We will begin with the assumption that modern aviation spirit has a Toluene value of 10, which is about the average value of American aviation spirit. At 10,000 feet the air density is 0.72, and at this density a compression ratio of 7.0 : 1 could be used with such a fuel, giving a theoretical limiting thermal efficiency of 38.6 per cent. and a theoretical limiting mean pressure of approximately 165 lbs. per sq. inch reckoned at ground level or 119 lbs. per sq. inch at 10,000 feet. Under these conditions let us now consider what power the engine could develop at ground level, keeping just free from detonation. If controlled by throttling the maximum indicated mean pressure would be approximately 95lbs. per sq. inch. If controlled

by varying the time of closing of the inlet valve it would be considerably higher, because for various reasons the efficiency obtainable under these conditions is greater and would be very nearly in the ratio of 5.25 : 7.0 × 165 (5.25 being the limiting ground level compression ratio for a fuel of Toluene value 10) or say about 122lbs. per sq. inch. If controlled by the addition of cooled exhaust gas the mean effective pressure, as shown previously, would be very nearly equal to the full available M.E.P. with a compression ratio of 5.25 : 1 or 140 lbs. per sq. inch.

In all cases let us assume that the mechanical losses of the engine are equivalent to an M.E.P. of 15lbs. (a fair average figure). Then the theoretical limiting brake mean pressure in the three cases would be :—

(1) 80lbs. per sq. inch.
(2) 107lbs. per sq. inch.
(3) 125lbs. per sq. inch, while at 10,000 *feet the brake M.E.P. will be 104lbs. in all cases.*

In all three cases the explosion pressure would be substantially the same, and little or no higher than at 10,000 feet—that is about 450-500lbs. per sq. inch. In the latter case it will probably be actually lower, because the principal effect of the exhaust gas is to slow down the rate of burning and so round off the peak of the diagram.

Assuming that the propeller torque varies as the square of the speed and directly as the density, then, if the engine is designed to run all out at 10,000 feet at 1,500 r.p.m., its maximum speeds at ground level will be approximately 1,100, 1,270 and 1,320 r.p.m. respectively. In the former case such an engine would probably fail to leave the ground.

From these considerations it seems clear that the principle of designing a very high compression engine for use at high altitudes and throttling it on or near the ground is not the right one. Of the three methods considered, the use of exhaust products appears to be the most hopeful as a means of permitting a very high compression engine to operate satisfactorily at low altitudes, and still have sufficient power to get rapidly off the ground.

The alternative method of dealing with the problem of varying atmospheric pressure is to maintain artificially ground level density in the cylinder at high altitudes by supercharging. From the point of view of engine weight there can be no doubt that this method scores heavily, for, although the strength and weight of many of the parts may be proportional to the density in the cylinder, there still remains a very considerable number whose weight is altogether independent of the pressure in the cylinder, so that the weight of the engine, as a whole, can only vary as the density plus a very large constant.

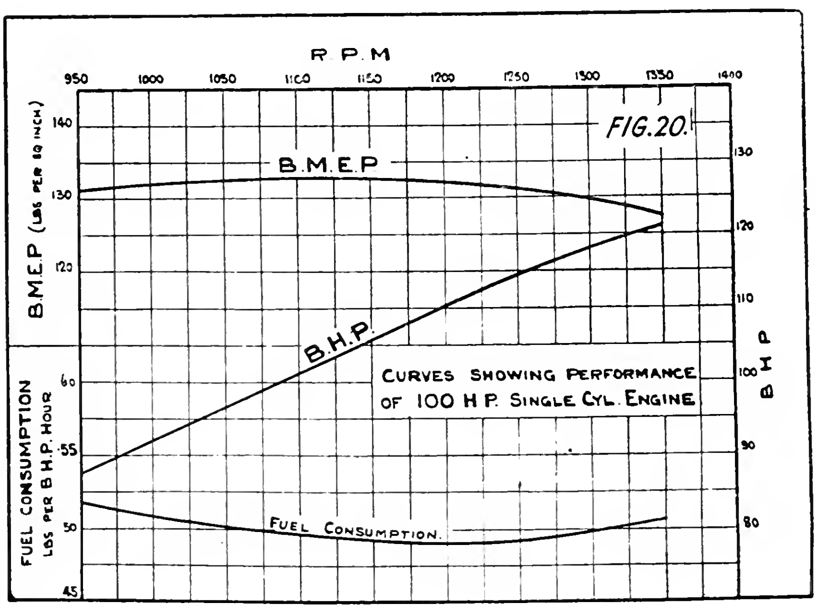
There are at least two possible ways of dealing with the supercharging problem, one by merely forcing more fuel and air into the cylinder by means of a pump or blower and the other by employing a supercharge of pure air in a stratified form.

Some four years ago the writer carried out a very extensive series of tests on this latter system, and obtained most encouraging results on two experimental engines, but had to break off these experiments and concentrate all his attention on engines for tanks. The results obtained were, however, so encouraging that further tests should be made. Apart from the obvious increase in power at high altitudes this system of supercharging provides a perfect and automatic compensation of mixture strength for altitude, and gives a considerable increase in economy, the consumption falling from 0.49lbs. per b.h.p. hour when running normally to 0.455lbs. when supercharging.

Limiting Size of Cylinder.

Designers of aircraft engines have, in the writer's opinion, shown quite unnecessary timidity in regard to the power output obtainable from individual

cylinders. So far as the writer is aware no one has yet had the courage to construct an aero engine with cylinders developing more than 50 h.p. each. Some $2\frac{1}{2}$ years ago, as a result of experience with large cylinders on tank engines, the writer was requested or rather challenged by the Air Board to design an engine for aircraft to develop 100 h.p. per cylinder. A complete design was prepared and after much delay a single cylinder unit was built at Farnborough having a bore of 204mm. and a stroke of 280mm. This unit has now been running on and off for over a year. Apart from a rather mysterious failure of the valve gear at first which has never been quite satisfactorily explained, it has given very little trouble, and no trouble at all which can be attributed to its large size. In view of the fact that its compression ratio is only 4.84 : 1 the results obtained are rather extraordinary and constitute, the writer believes, quite a record for so low a compression. This single cylinder unit develops 120 b.h.p. when running at 1,350 r.p.m. with a consumption of only 0.493lbs. per b.h.p. hour at its normal speed of 1,250 r.p.m. corresponding to an indicated thermal efficiency of 31.2 per cent., or within 4 per cent. of the limiting value for this compression and an indicated mean pressure of 150lbs. per sq. inch.



These results will, the writer hopes, help to dispose of the myth that very large cylinders can only operate with relatively low mean pressures and at a low efficiency.

Mr. A. J. Rowledge then delivered the following lecture :—

THE INSTALMENT OF AN AEROPLANE ENGINE.

It has been remarked that more accidents occur due to installation than to engine failure. If this is true, or even partially true, the subject is one that is well worth careful consideration and discussion to see what we can do to eliminate the causes of trouble in view of our responsibilities to the flying public. It is a subject that can be approached in many different ways. We can take the smaller points of the detail arrangement of parts and this is sufficiently important to warrant the whole Paper. Then there is the question of the position of the motor or motors, whether a central engine-room with shaft and gear drive to the

propellers is desirable. We may also consider whether the propeller should be direct coupled to the crankshaft and whether gearing should be used at all. In fact, the subject can be very easily made too wide, and I will limit myself to a few definite points, first by limiting myself to water-cooled engine installations and then as regards data and illustrations to one particular engine.

With regard to the particular engine I am taking the Napier "Lion," as in this case I can be responsible for the accuracy of the data which is easily available to me. I hope people who have comparable data, particularly with regard to air-cooled types, will give their experience in the discussion.

In a complete aero-engine installation the main factors are weight, power and reliability. When considering weight, we should take the whole weight of the power plant, including tanks and fuel.

In talking of power, we should take the thrust horse-power, and if possible deduct the drag due to cooling when making comparisons.

I will take first the part of the subject which is worthy of greatest attention—the detail troubles which may prevent a perfectly good engine from functioning properly.

What are these troubles? They are mainly :—

(1) Failure of the petrol supply.
(2) Failure of the oil system.
(2) Failure of the ignition.
(4) Overheating.
(5) Fire.

I think engine-starting accidents should be included with these, as means can be taken to prevent them with any engine, except perhaps the rotary type.

1. Petrol System.

Now the petrol system is undoubtedly difficult to make absolutely free from troubles, but a little modification and experiment should cure most of them and reduce the care the system requires in use.

The main petrol tank is usually so low that the fuel has to be pumped from it, generally to a gravity tank feeding the carburettors. It is often very difficult to arrange a gravity tank with sufficient head, and the arrangement of a wind-driven pump delivering to a junction box with branches to the carburettor and the gravity tank gives a useful addition to the available head when flying. A cock must be fitted between main tank and the junction box to prevent the pump pumping air into the system when the main tank is empty, and to prevent petrol from the gravity tank running back to main tank when standing. With a suitable pump and relief valve a cock may be fitted between the gravity tank and the junction box. In the Airco machines the cock is combined with the junction box in such a manner that by the movement of one handle the feed can be either from the main tank or the gravity tank, or both. It is necessary to provide an overflow from the gravity tank leading to the main tank to take the excess petrol supplied by the pump. A flow indicator fitted in this pipe will show when the main tank is empty and is often fitted.

Engine-driven pumps will almost certainly come into general use, and this step will improve the reliability. Pumps are usually fitted in duplicate, and especially in large machines a hand pump is also provided to feed the gravity tank.

In very large multi-engine machines, particularly for military purposes, the whole system is much more complicated, but I do not propose to deal with them in this Paper.

2. Oil System.

Oil pipes are a constant source of trouble. There is one sovereign remedy—do away with them. I quite expect one day to see an installation with only one oil pipe from the reserve oil tank to the engine, and for flights up to 3 or 4 hours, none at all. This means, of course, that the oil tank will again become part of the engine. In making this statement I am considering mainly civil aviation machines as certain military ones run under somewhat different conditions, and the same simplicity of arrangement is not always possible.

Sufficient oil cooling is easily provided. All installations of new design should be fitted with thermometers to check the oil temperature.

Good and easily accessible oil filters must be fitted, as they should have frequent attention.

3. Failure of the Ignition.

Ignition failure is usually a matter of the magneto, either due to unreliability of the magneto itself or due to the machine suffering from an oil or water bath or too much heat. With regard to failure of the machine, I am afraid that to go into magneto design from this point of view would occupy too much space for its discussion to be considered in this Paper. Trouble from the other sources will disappear very quickly as more aeroplanes are built.

It is essential to fit two entirely independent ignition systems to ensure reliability, and with the size of cylinder usual in aero-engines the gain in power from having two plugs in each cylinder is considerable.

It is usually possible to find from among the various plugs on the market one that will suit any particular engine and be reasonably reliable.

If the installation is thoroughly gone over on the first experimental machine, the correctness of the general design should be established, so that only the detail parts require attention.

With an adequate supply of petrol the float feed certainly requires attention. We make our floats much too small, with the result that to obtain the necessary effort to close the needle valve they have to be made too thin and flimsy. A little more weight—a few ounces—and I think the float feed can be made beyond reproach as a reliable unit. A float feed can be made to work satisfactorily with a head of only 18 inches if the size is not restricted.

The pipe lines should be carefully studied so that air is not trapped, and then we come to one of the major troubles—the pipes themselves and their joints. The life of rubber joints is much too brief, especially if benzole is used in the fuel, and some change is urgently required. I believe that if we adopt, as has been suggested, a fairly heavy gauge steel tube for our pipes and use rigid joints, we should find a way out of the difficulty. The pipes should be arranged so that deflection is taken in torsion and the tube designed so that it is not overstressed by movements of the frame carrying it.

Carburettor float chambers will again require altering to be strong enough to take the feed connection when all steel pipes are used, and the connection to the petrol tanks will require careful consideration as well to prevent the fairly rigid pipe from causing leaks.

The fitting of an adequate filter is, of course, necessary.

Improved means for telling the pilot the amount of fuel he has left in his tanks is desirable.

4. Overheating.

With respect to overheating this appears to be a matter of having sufficient cooling surface allowed for the worst conditions and fitting shutters to keep the engine warm under more favourable circumstances. Several ingenious arrangements have been made to reduce resistance loss when the whole of the cooling is not required. The Airco 18 and the Fairey installations are both examples of one of the latest schemes, each having the radiator under the engine with shutters in the nose to control the air flow through the radiator.

If the cylinders are smooth they should be used as cooling surface as much as possible, as a square foot of surface here is much more valuable for cooling than a square foot of radiator tube.

A well-arranged water system gives very little trouble, and difficulties under this head should not exist, at all events in temperate climes.

5. Fire.

The first rule to make to lessen fire risk is that the carburettor intakes should be carried outside the cowling to carry any flame from a back-fire clear and that all petrol due to flooding should drain directly overboard. It is also desirable that the engine should have the cylinders grouped as regards mixture pipes, each group having its own carburettor, so that in the event of trouble due to valve failure in one group, the remaining groups will carry on and suck out any fire in the faulty one.

Exhaust pipes require to be suitably carried to prevent overheating of any part of the machine and to be strong enough not to burst open at some inconvenient place.

The magnetos should be of a fireproof type, and all the wiring arranged so that a spark from the ignition cannot start a fire.

The position of the petrol tanks and the arrangement of the pipes are both very important. There should be the minimum amount of petrol piping in the engine compartment, and certainly the lower the carburettors are in the installation, the less the risk that need be run.

When the installation has been made as safe as possible by attention to the above points and to preventing any accumulation of petrol or oil in pockets in the engine compartment, a fireproof bulkhead should separate this compartment from the rest of the machine. Any pipes or control rods that pass through the bulkhead should have fitting bushes.

We shall thus considerably reduce the risk of fire, and in the event of a flame starting it will quickly burn out if it cannot reach any inflammable material.

6. Engine Starting.

Engine starting should always be accomplished without propeller swinging; if necessary, by fitting gearing and a crank handle.

I have very little sympathy with electric starters owing to their weight and complication. An engine should be able to be started as long as there is petrol in the tank and not be dependent on the small batteries that can be carried.

The Lion engine is fitted with what we usually call a gas starter. It consists of a vaporiser connected to the engine mixture pipes by a pipe controlled by a cock. A hand pump is provided which blows through the vaporiser, charging the mixture pipes and cylinders with a suitable mixture for starting. To enable the cylinders to be charged, one each of the inlet and exhaust valves can be

held open. A suitable cock is provided so that the pump can scavenge the cylinders with fresh air to give constant conditions in the cylinders before charging. The usual hand magneto is used to provide the spark for starting.

These engines can always be restarted in the air if the machine has sufficient height by lifting the valves, the engine immediately windmilling. When it is spinning the valves are dropped and the ignition switched on and the engine is restarted.

I confidently expect to see engines started easily from the pilot's seat with certainty in the worst weather, as we can now start our engine under good conditions.

Engine Controls.

All controls should be by rods and levers, and flexible cables should be discarded.

The throttle and mixture strength levers should be mounted together and so arranged that when the engine is throttled down the mixture lever is brought back to the right position, otherwise if the pilot forgets to return it he may stop his engine when opening up at a lower altitude.

I prefer the interconnection to be on the control quadrant and not on the engine, as it reduces the strains in the connections.

The ignition control is probably best coupled to the throttle control as it is certainly a safer arrangement and there is no need for it to be left to the pilot.

Other Points.

The choice of a suitable propeller is very important as affecting engine reliability.

Personally I favour a machine with a good reserve of power, using a propeller that will allow the engine to develop full power when getting off and climbing.

It is surprising what good results can be attained in propeller design in the direction of keeping down the range of engine revs. One of the best cases I have come across on our engine is from 1,950 stationary on the ground to 2,150 all out flying level at about 120 miles per hour.

This point is particularly important with high compression engines, which are liable to detonate badly if run for long at full power on the ground at low engine revs. This point must be familiar to all drivers of motor cars whose engines pink when climbing hills at low speed.

If an engine is of light weight per b.h.p. and economical when running at light loads—particularly the latter—there is no disadvantage, and a good reserve of power is left for climbing and for maintaining schedule time under adverse weather conditions.

In the maintenance of machines in service it is important to have all parts as accessible as possible, to have as little cowling to remove as can be arranged and that amount easily detachable.

One great advantage of placing the radiator elsewhere than in the nose is that provided a smooth engine is used, it requires little cowling. Our engine, as placed in the Airco 18, has the upper part of the engine exposed, and the plugs can be changed without removing any of the cowling.

ACTUAL INSTALLATIONS.

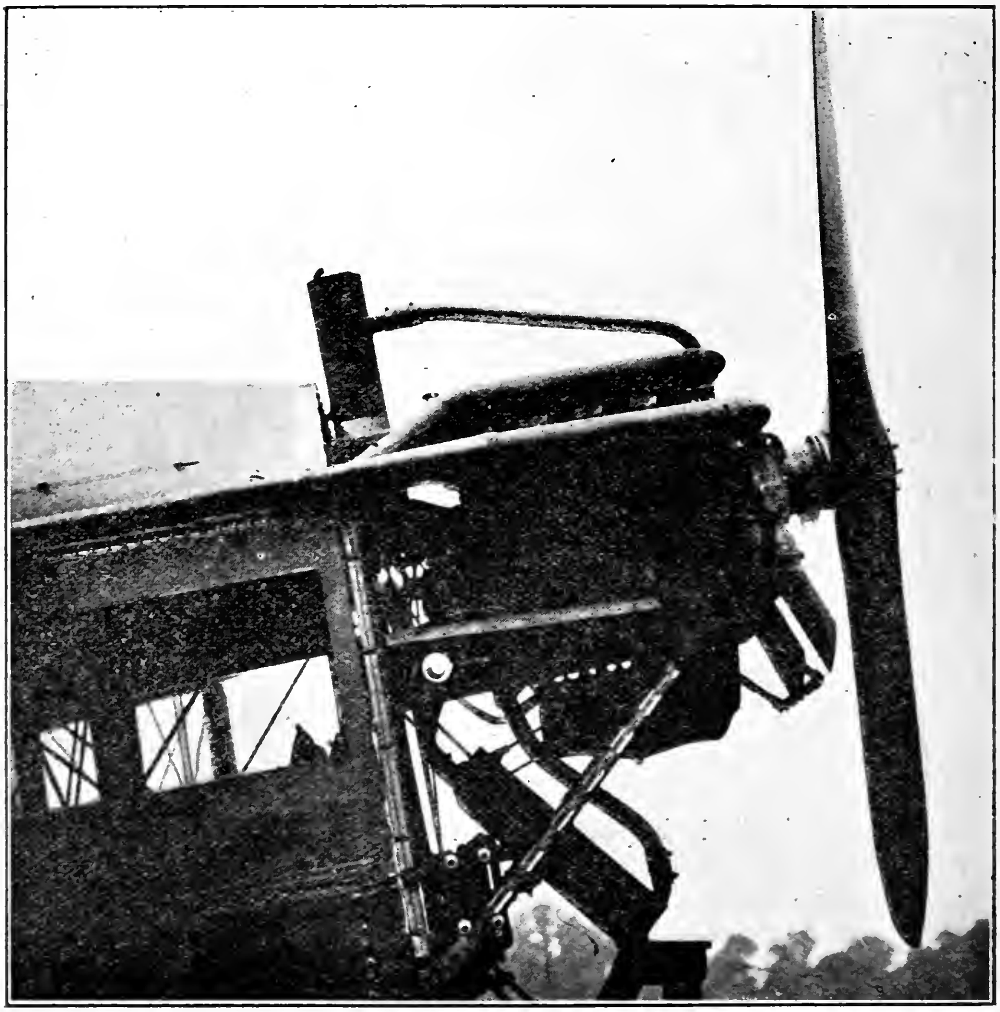
Airco 18.

My first illustration shows the installation in the Airco 18 used on the Paris service of the Aircraft Transport and Travel Co.

The weight of the various parts of the power plant are :—

Motor	860lbs.
Cooling	233 ,,
Tanks	142 ,,
Framework and cowling	110 ,,
Fuel and oil	875 ,,
Exhaust manifold, propeller and miscellaneous	194 ,,

making a total of 2,414lbs. or



Napier "Lion" Engine Installation in Airco 18.

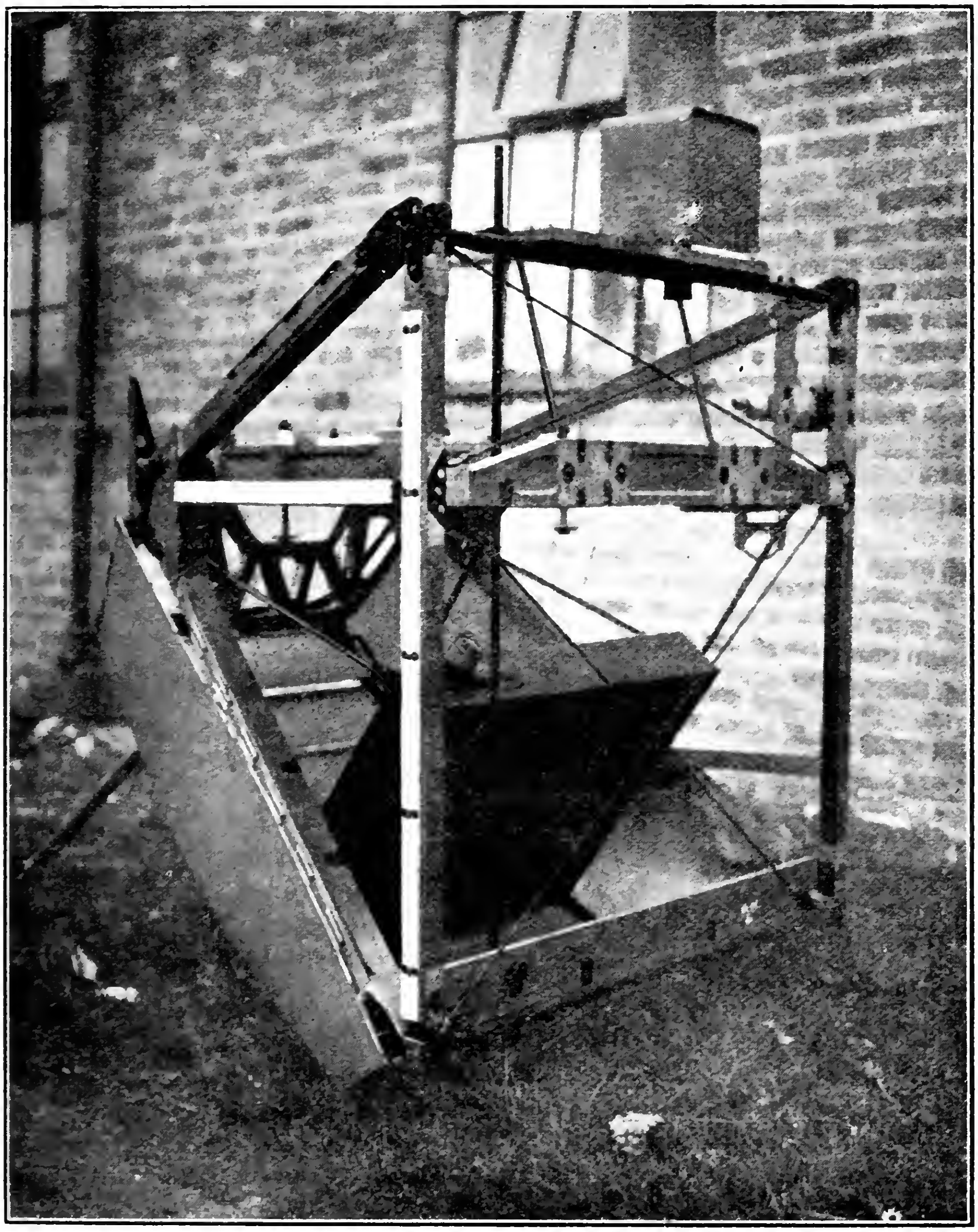
5.36lbs. per b.h.p. including the weight of the whole framework carrying the engine and engine cowling. The amount of fuel used in service is from 20 to 25 gallons per hour, and varies with the weather conditions. The weight of fuel included in the above is sufficient for 4 to 5 hours flight.

The whole framework carrying the engine is detachable by removing four bolts at the corners of the front end of the cabin, making it possible for a spare nose to be kept with the engine installation complete, ready to replace the ones in

service with the minimum delay, preventing the necessity of laying up the machine whilst the engine is being overhauled.

The petrol tanks are carried in the main body.

The engine is started by the special system of the engine makers, the controls



Detachable Nose of Airco 18.

and pump handle being all accessible under the rear of the engine frame, the height of the fuselage from the ground making this a convenient position.

A complete description of this machine has appeared in "Engineering" of August 20, 1920.

I have so far talked of the installation weights as lbs. per b.h.p. including fuel, and this rather hides the importance of the weight per b.h.p. of the engine itself, and I should like to just touch on this question very briefly.

Taking the Airco 18, which has a total flying weight of 6,730lbs. when

carrying a useful load of 1,470lbs.; if the engine weight were increased by ½lb. per b.h.p. or 225lbs., in order to carry the same actual useful load with the same efficiency, that is, with the same flying weight per b.h.p., the h.p. would have to be increased to 533 and the total flying weight by 1,120lbs. to 7,980lbs., making a machine much more expensive to run and of greatly increased first cost, owing to the increase in size.

Fairey Amphibian.

This machine has the engine mounted in the nose. The radiator is mounted in the fuselage under the engine. The reserve water tank is carried in the front of the top plane and the outlet water pipe from the engine is carried through it, being perforated to allow air or steam to escape from the circuit. The tops of the cylinder blocks projecting through the cowling, considerably assist in cooling the engine.

The main petrol tank is carried below the engine level and between the planes. A gravity tank is fitted immediately behind the water tank in the top plane.

The oil tank is carried close to the back of the engine just below the bearers.

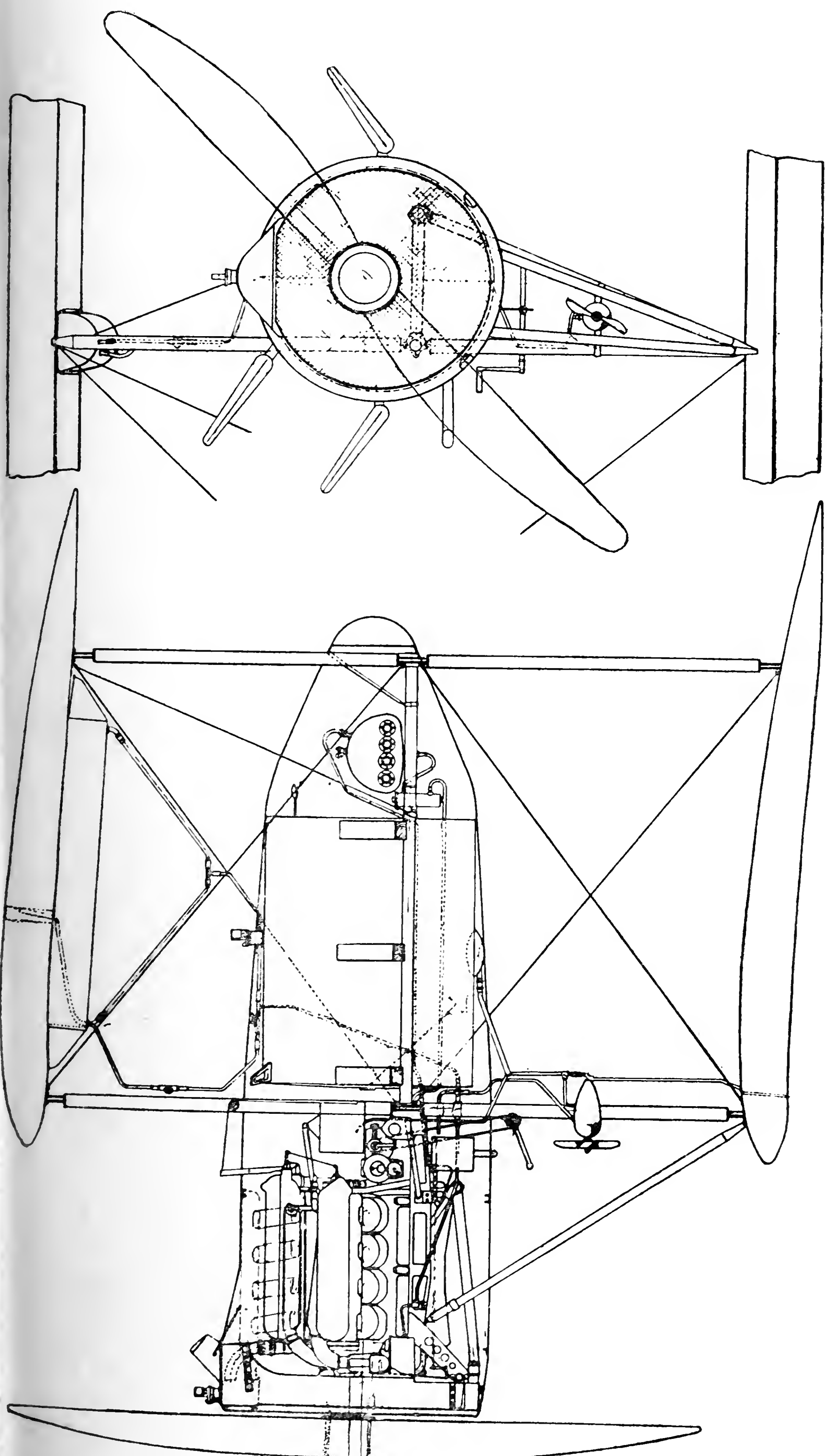
The engine controls are all coupled by means of rods to levers conveniently placed in the pilot's cockpit.

Handley Page W.8.

The machine is fitted with two engines, each forming a self-contained power unit comprising engine, fuel tanks, oil tanks, radiator and water.

The engine rests on armoured wood bearers which are supported by a triangulated steel tube structure underneath and two vertical tubes above, braced by ordinary R.A.F. wires. This arrangement provides for the engine and tanks being offset outboard one foot from the point where the frame is attached to the plane hinges, thus saving two feet on the folded width of the planes without restricting the propeller diameter. The absence of tubes and bracing above the horizontal tank and engine bearers on the outboard side enables the engine and tank to be removed with the minimum of trouble. The radiator with water tank and altitude shutters is carried by flexible clips from the end of downward extended arms bolted to the front of the engine bearers and stayed at the top to the vertical tubes. A fire-proof partition is fitted which entirely isolates the tanks from the engine. The 10½ gallon capacity oil tank fitted with air cooling tubes is placed across the tank bearers at the rear and connects via a large bore cock with the Napier oil strainer placed alongside. The tank is below the level of the engine connection when the machine is resting on the ground. The main petrol tank is of rectangular section placed between the tubular bearers and fixed thereto by U-bolts. A vertical contents indicator is fitted to the top visible from the pilot's seat and working over a scale 5in. long, is worked by a quickly detachable float arm. The petrol system comprises a large filter with detachable gauze of 35 square inches area placed inside the bottom tube fairing and connected up to main tank sump, from the filter petrol flows to the "Vickers" centrifugal wind-driven pump which feeds straight to the carburettors via a pilot-controlled cock, the surplus passing up to the gravity tank under the top wing and then overflowing from there back to the main tank via the flow indicator let into the fairing of the vertical tube and visible from the pilot's seat.

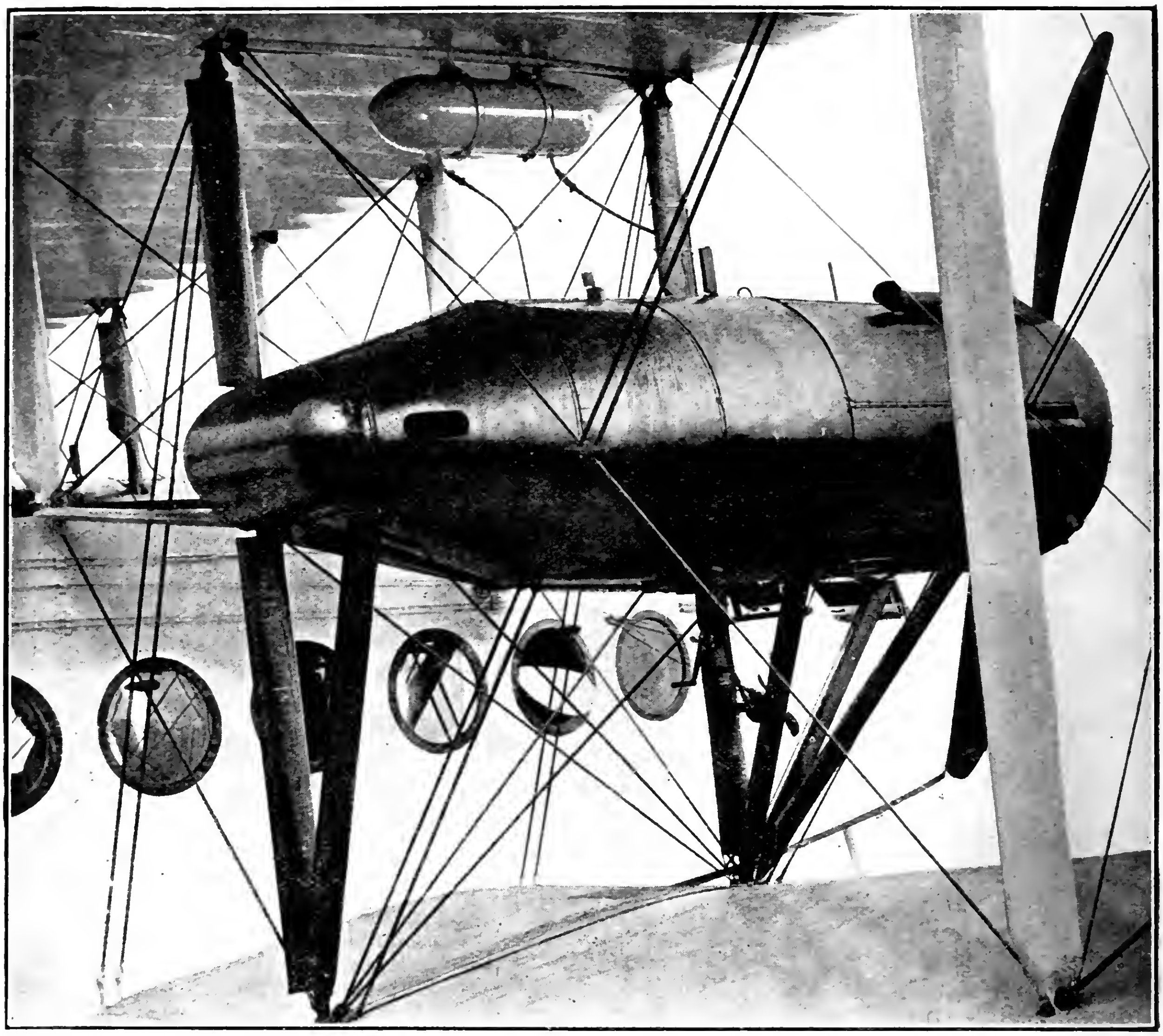
Two additional small A.G.S. type filters are fitted close up to the carburettors and a hand pump is provided in the pilot's cockpit for use when starting up. In the event of the pumps failing the gravity tank feeds to the carburettors until empty, or one pump can be made to supply both engines via the fuselage. A cock is provided for draining the gravity tank when machine is in dock. The engine starting handle is fitted to a cross shaft below the cowling and drives to



HANDLEY PAGE TYPE "W.8"

C.A. OF NAPIER "LION" ENGINE MOUNTING

the engine by chain. The starting gear, consisting of vaporiser, pump and starting magneto, are shown on the drawing. The starting clutch and valve lever are fitted with cables and rings placed in a convenient position. The aluminium cowling is fitted to the framework in panels which can be quickly hinged open or removed altogether. A platform is built into the bottom plane for use of mechanics.



Installation of Napier " Lion " Engine in Handley Page W.8.

Vickers' " Viking III."

The engine is located high up in the space between the upper plane and the deck of the hull, the principal supports being four steel tubular struts which spring respectively from the four main plane strut fittings on the deck. In front elevation the main plane struts diverge from the deck fittings, and the engine struts diverge in such manner as to support the longitudinal engine bearers at the transverse pitch defined by the holding down bolts of the engine. The bearers are of ash, being connected transversely by steel tubes at their front and rear extremities, and all four sides of the truncated pyramid thus formed are braced with streamline wires.

The engine is mounted as a pusher, so that the power end is the rear with reference to the machine.

The radiator is supported on trunnions which are mounted on forward extensions of the ash bearers, tubular stays being carried from the upper part of the radiator casing to the under side of the front main plane spar. The whole of the front surface of the radiator is shuttered.

The three engine manifolds conduct the exhaust gases forward, *i.e.*, towards the radiator, this direction being reversed by the application of U-shaped extensions which discharge the gases backwards at a safe distance from the propeller.

Twin oil tanks are slung externally along the ash bearers, and the Napier oil filter is clamped upon the front transverse tube at about the same level.

The engine controls are actuated by a positive system of push and pull rods which pass up from the pilot's cockpit by the front starboard leg of the mounting and are connected up to levers on transverse shafts supported by the brackets which support the radiator.

The starting shaft of the engine is extended to pass through a bearing on the front port main plane strut, and is worked by means of a crank handle of standard type.

The Napier vaporiser is supported on a bracket high up between the radiator and the engine, the valve operating lever being connected through an extension to a vertical tension rod which passes down behind the radiator and is fitted with a T-handle.

A low trough-shaped cowling is applied to the engine bearers and fairs in the lower part of the radiator, oil pipes, etc., but the cylinder blocks and manifolds are completely open to the air.

The air intakes, of aluminium, are carried down through the cowling, converging towards the centre in order to avoid screening by the struts.

The Vickers' wind-driven centrifugal petrol pump, which supplies the power for the petrol system, is located on the rear port main plane strut.

The weights of the various parts of the power plant are :—

Motor with turning gear	890lbs.
Cooling	275 ,,
Tanks	78 ,,
Framework and cowling	75 ,,
Fuel and oil	577 ,,
Exhaust manifold, propeller and miscellaneous	170 ,,
making a total of	2,065lbs.

or 4.58lbs. per b.h.p. The fuel economy of this machine is very good. At Martlesham in the Government trials it flew at 82 m.p.h. with a fuel consumption of 14.2 gallons per hour.

Westland Six-Seater Limousine.

The engine is installed in an all steel separate tubular mounting, rigidly braced by cable and attached to the front fuselage by 10 bolts.

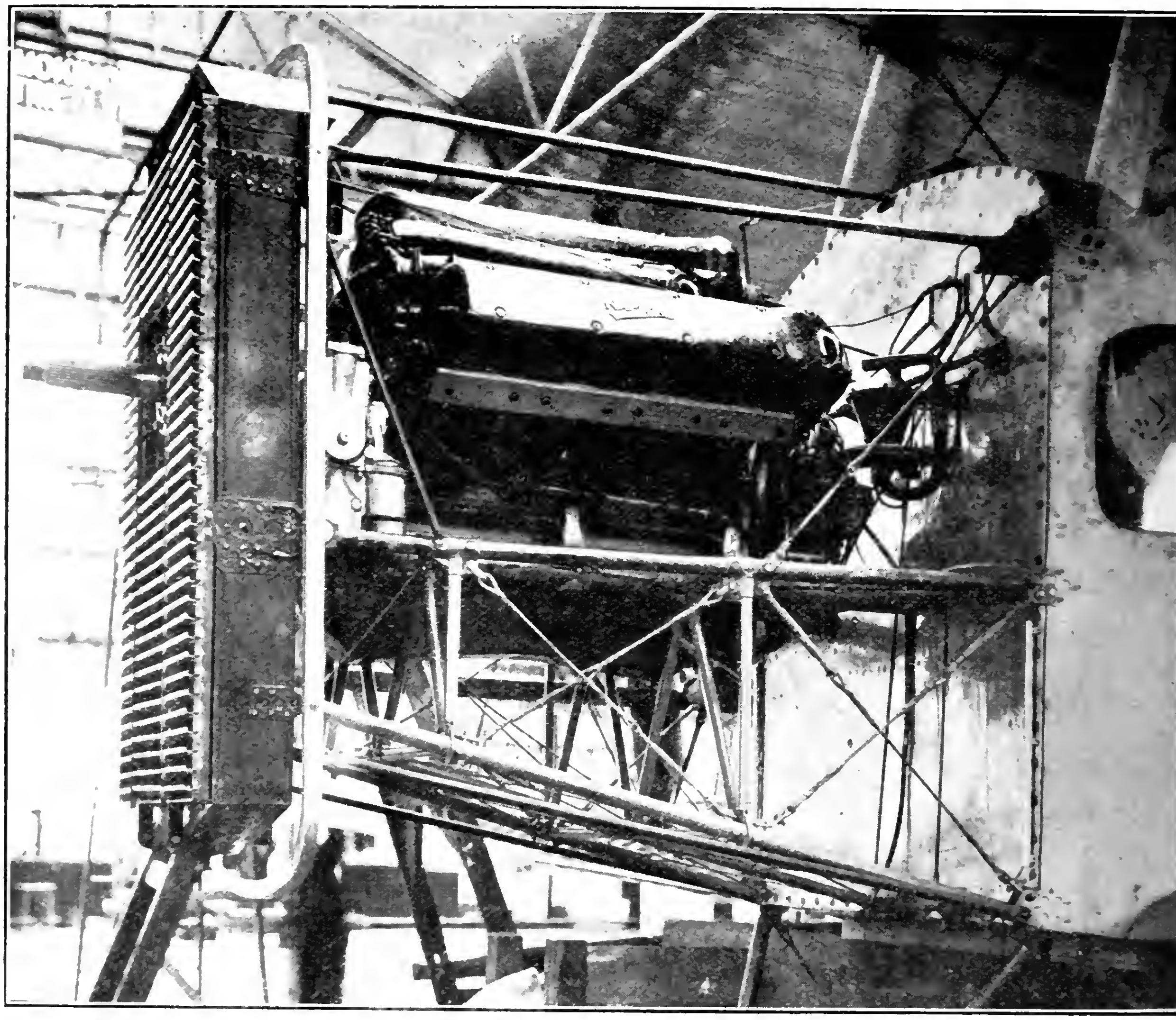
The engine is directly bolted to the two main bearer tubes by six bolts, and when in place is very accessible.

The top and bottom side tubes of the structure are arranged so that their extensions form the support for the radiator.

The cowl and cowl frame are independent of and are not supported by the radiator, making the removal of the latter a very simple job.

The whole of the engine installation is separated from the rest of the machine by an aluminium and asbestos bulkhead; in fact, fire prevention has been studied

very carefully in this machine. The carburettors, of course, suck from outside the cowling. Two main petrol tanks are carried, one on each side under the bottom wings; each is fitted with a wind-driven pump delivering the fuel to a gravity tank carried in the front of the top plane, whence the carburettors are fed. None of the pipes enter the main fuselage behind the fireproof bulkhead; the pipes are very accessible and the renewal of the jointing material is much simplified.

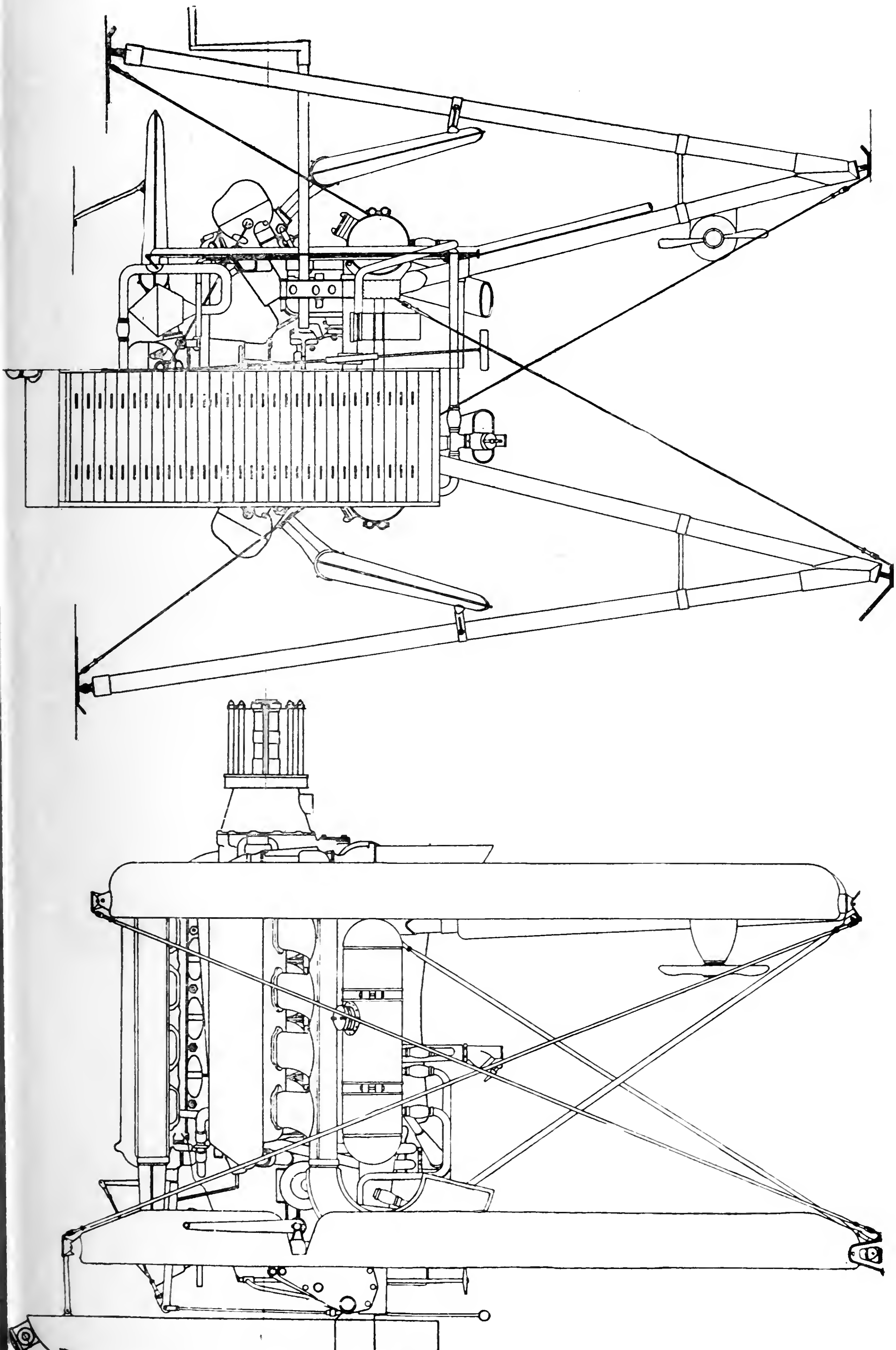


Westland Napier 6-seater Limousine (Government Aircraft Competition, 1920, small class—engine installation).

The engine fitted in this machine for the Government trials was fitted with gearing for a crank handle for starting, but no handle was fitted, the gas starter being relied upon with very satisfactory results. All the controls and the charging pump are placed so as to be get-at-able from the pilot's seat. A hand turning gear is now fitted to these engines for starting from cold in bad weather, keeping the gas starter for favourable conditions and as a very efficient primer in connection with the hand turning gear.

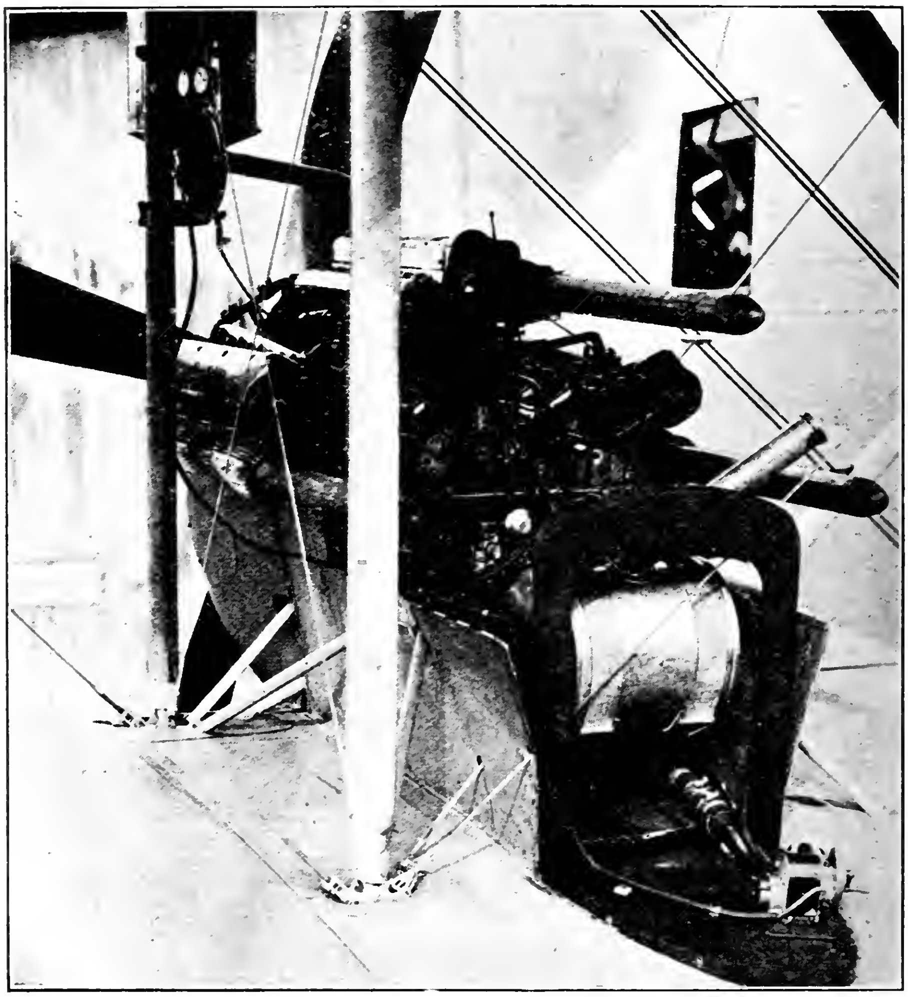
Boulton and Paul "Lion" Twin-Engine Machine.

I am including this illustration particularly to show the method of dealing with the exhaust designed by Mr. North. This consists of ribbed aluminium castings bolted to the cylinders with steel pipe extensions. The ends of the



NAPIER LION ENGINE MOUNTING IN VIKING MKIII

pipes are closed and the gas escapes through narrow slots. This arrangement is quite effective as a silencer; the castings and pipes being in the slip stream are kept surprisingly cool, and this system appears to be worth much wider trial.



Installation of Napier "Lion" Engine in Boulton and Paul twin-engine machine.

In conclusion, I should like to thank particularly the various firms who have so kindly placed illustrations and data at my disposal, which have been invaluable in the preparation of this Paper

DISCUSSION.

Brig.-Gen. R. K. Bagnall-Wild said he had not had an opportunity of seeing the Papers before, so he would make his contribution in writing.

Wing Commander T. R. Cave-Brown-Cave said the two Papers were extremely valuable. Mr. Ricardo's covered a wide range of experimental work, mainly directed to showing how it would be possible to obtain greater fuel economy. The importance of fuel economy was not always realised and some figures based on recent considerations of airship transport would be of interest. The saving of the *price* of a pound of fuel was comparatively unimportant. The important

gain was that by eliminating a pound of fuel a pound more merchandise could be carried, and the saving was the price of carrying a pound of merchandise the whole distance. To take a typical airship route, the cost of carrying one pound was 2s. 10d. That might be regarded as too low, but if one liked to take it as 10s. his point was even clearer.

A question had arisen whether an explosive mixture of hydrogen and air was more easily ignited than one consisting of nearly pure hydrogen. He wanted to ask Mr. Ricardo to give some more information on that point, and also whether dilution with nitrogen or oxygen would increase or decrease the difficulty of ignition. Mr. Ricardo's Paper showed great originality. Taking it in conjunction with his Paper read recently to the British Association, one realised what enormous progress was being made. He was sure those who had not read the Paper, but had only heard the abstract read, did not realise completely what an amount of information and advance there was in it. He knew of no more refreshing experience than to go to Shoreham and see in Mr. Ricardo's laboratory the admirable arrangements for research work, and when, after that, one saw his two Papers, one realised the speed and value of the progress being made. It did seem that something really good was going on in engine research.

He was much pleased with one point, particularly, in Mr. Rowledge's Paper. The description of the machine in which the whole engine and its fittings could be removed by the withdrawal of four bolts announced a very valuable development. He had pleaded at a lecture of last session for airship power cars to be made as easily changed as the locomotive of a railway train. Mr. Rowledge's design certainly came very close to that ideal.

Major H. E. Wimperis said some members of the Society would be chiefly interested in the development of the internal combustion engine as such, whilst others were more concerned in what to do with the engine when they had got it. Speaking as one of the former class, he felt now that any one of the great engineering institutions would have been glad to have had Mr. Ricardo's very able Paper. This Society was therefore very fortunate. It was interesting to come once again across a discussion of such things as stratification and quality "governing." The question of quality versus quantity regulation was an old one and it was now being raised by Mr. Ricardo for aero engines. With the earlier kinds of engines it was a very vexed question. The aero engine, like the motor car engine, had adopted the regulation of power by varying the quantity of the gas; we were now asked to consider whether it would not be of advantage to vary the mixture, *i.e.*, the quality instead of the quantity. Would Mr. Ricardo, he asked, expect to find with the aero engine the difficulty with ignition setting which was always found by those who tried quality governing with the predecessors of the aero engine? The question with regard to stratification was important because the reliability of the aero engine depended very much on the ability to run at cruising speeds—not at full power. To go to the other extreme, the motor car ran at 30 per cent. full load most of its time. One started at 100 per cent. and went down to 90, 80 and 70, and as one tried to get a better and better figure, it became more and more important that the thermal efficiency should be maintained. Mr. Ricardo now suggested that the adoption of the stratification method of fuel supply would improve the efficiency. As to the effect of the addition of exhaust products, he would ask Mr. Ricardo a difficult question. We all know that the admission of a fraction of the exhaust products had the effect of minimising the tendency to detonation, but could he say why?

Air Commodore H. R. M. Brooke-Popham congratulated the audience on their good sense in coming to listen to these Papers. Mr. Ricardo's Paper was particularly valuable in showing the possibilities of progress. It was an important thing to show the public that aviation had by no means come to the end of its

tether, because there was rather a tendency among certain classes to think aviation had shown all it could do, and had not quite come up to what was claimed for it. They should take every opportunity of showing they were only just touching the fringe of the subject. He was struck by the mounting Mr. Rowledge showed for the Airco 18. That was particularly important from a military point of view and it should be brought into other machines. The time taken in changing engines had an important effect on the number of machines available for work each morning. If an engine took 48 hours to change it meant that a larger proportion of aeroplanes was out of action every day. Sometimes in the last war repairs could not be effected in a night, because there were delicate adjustments and fitting to do, but if machines could be designed so that the engine could be changed by moving four bolts and putting four bolts back again it was an enormous step in advance. Magnetos were not as reliable as they should be. The difficulty was not electrical, it was mainly lack of attention to mechanical details. He saw no reason why the British magneto should not be a great deal ahead of any German magneto. We knew the electrical defects, and it was simply a question now of paying more attention to mechanical details.

Mr. Chorlton (Sir Wm. Beardmore and Co.) added his congratulations to the Authors. He thought the question of the installation was almost more important than that of the engine. The installation in the Airco 18 was a very excellent arrangement with a fire bulkhead and the whole of the engine and tanks and gear demountable very quickly. No doubt that type would be further simplified and improved. He imagined that we should soon have aeroplanes in which there would be an eyebolt at the top of the engine unit, so that a crane run overhead could lift the whole section off, so that it would be taken away and another take its place in an hour. He believed that something like this would be essential if flying was going to be a commercial success. There was another aspect different from those the Authors had dwelt upon. Two important considerations were weight and quality. It was rather unsatisfactory after hearing such excellent scientific Papers as they had heard, to know that on the Paris service the light weight engine, if made reliable, was a better commercial proposition than the economical engine. So it struck him that if Mr. Rowledge were to go out and design an extremely light weight engine and get it made at the Napier works he would get still better results than he had attained so far. It had been shown clearly that the best engines had been made by those firms accustomed to making the best class of motor car. That had been so throughout the country. It was no reflection on the designer, but it was a fact. When one came to economy, the saving that could be made in economy on flights of three hours was much smaller than the gain by having the least possible weight of engine. The price paid by the passenger was so high, as Commander Cave had found out, that the gain was great for long flights, for short flights it paid to go in for the light engine. He thought Mr. Ricardo's remarks were more applicable to airship work than to the standard aeroplane flights. With regard to the doping of fuel, it was evidently going to end up by being the regular thing, and a standard spirit would be prepared which would enable those high efficiencies to be obtained. It was curious that they were getting more by dope than by anything else. In reference to stratified charging, Mr. Ricardo and he years ago spent a great deal of time on this, and on a large engine, in 1912, he got with stratified charging a consumption of under 6,000 B.Th.U., which was, and he thought still continued to be, a record. He was entirely with the Author in saying that it was the best thing to do, and it met the cruising conditions for long flights admirably. Again, in his opinion, it was more the thing for airship work than for aeroplanes. With regard to increase in the expansion stroke—longer expansion than compression—that was another excellent thing to do; and it was possible to do it in another way that had possibly other advantages. The stroke in a radial engine could be varied by an eccentric on the crank pin, and one could start a flight with a long suction

stroke and short power stroke and continue the flight with a short suction stroke and long power stroke, varying the power and the economy greatly. Then they had their old friend cooled exhaust. This nearly always cropped up when they were in difficulties and cured them. Though it was an ancient thing it had been left for Mr. Ricardo to put it in its right place and make the most effective use of it. He had known it and used it for 15 years, but to a limited extent, for coke-oven gas, where there was 40 to 50 per cent. of hydrogen, was not safe running, for pre-ignition could not be got without it. It was only in the last year or two that Mr. Ricardo had taken it in hand and shown what increased economy might be obtained by its now scientific use. On the question of large cylinders, Mr. Hamilton of the Premier Gas Engine Company had worked up to between 120 and 140lbs. mean pressure for 20in. cylinders a long time ago, so they should not be deterred from going to something larger even than the 8in. cylinder Mr. Ricardo had spoken of.

Captain G. T. R. Hill said the detachable type of engine mounting described by Mr. Rowledge came very near the ideal of quick change and quick replacement, as shown by the rotary engines. In his squadron during the war they had De H.2's with 100 mono engines and they got their engines changed during the night without difficulty. This could not be done anything like so easily with other engines.

The whole question of installation seemed rather to have fallen between two stools. The engine designers produced an engine and the aeroplane designers produced their machines, and there was not enough co-operation between the two in modifying their designs to fit together easily. For example, the Hispano-Suiza engine, which was widely used at the end of the war, was not a convenient engine to build into a fuselage. The flange of the engine crankcase, which was bolted on to the fuselage, was much too narrow to fit the longerons of the machine, and engine bearers with narrower centres had to be fitted between the longerons and much cross-bracing put in to make the structure stiff enough to connect the engine rigidly with the longerons. In his opinion, the best way to make an engine easy to fit to a fuselage was to follow what the Rolls-Royce makers had done, that was to fit feet which could be bolted on to the crankcase. These feet could be made of variable length, according to the design of fuselage, and could be clamped on to the longerons at any points desired. He thought the nose of the fuselage should be made quickly detachable from the rear portion, and instead of having spare engines one could have spare noses of fuselages, complete with radiator and oil tank, ready to fit on to an aeroplane whose engine required overhaul. These noses could be bolted on to a dummy fuselage for test purposes, and run up with a propeller of small diameter, which would give the high velocity of slipstream necessary for sufficient cooling with the standard radiator when run on the ground.

With regard to the position of the engine controls in the cockpit, in his opinion they had got to the stage where they ought to have a standard position of the throttle lever and switch. These, he suggested, should always be on the left of the pilot, close to his left hand, so that no groping about would occur in an emergency. In two and four-engine machines there should be one master switch to switch off all the engines in case of need.

He would like to see a complete gravity system for the petrol coming into more general use. Most forced landings were due to petrol failure and petrol failure was practically always pump failure, and pumps never could be made as reliable as gravity. Against the all-gravity system it might be urged that the tanks in the wings were not of the optimum shape from a lightness point of view, but that was so small a disadvantage compared with the reliability obtained that he thought a move should be made in that direction.

As regards the desirability of using a propeller which had nearly constant revolutions at all speeds, this was realised with a coarse pitched propeller, and as such he believed it was theoretically rather less efficient than a fine pitched one. In practice, however, it did not appear to make much difference to the performance of the aeroplane, and he much preferred flying with a coarse pitched propeller, especially in war time, as the engine did not tend to race so badly in a dive.

He had analysed the petrol consumption results obtained at Martlesham on the land-going machines in the recent Government competition, and he could not make the consumptions, on the whole, come down to anything like the figures given by any maker of engines. There was little data available of actual consumptions in the air. When making an analysis of such as the Martlesham figures there was always a certain amount of guesswork, but he had not been able to make any of the consumptions come to appreciably less than 0.6 pints per h.p. hour and many stood at nearly 0.8 pints. That was a point to which more attention should be paid, and possibly it might be necessary to apply a correction factor to the engine makers' figures when estimating what the actual consumption would be on a commercial service.

Col. Bristow said, as he had not had an opportunity of looking at the Papers, he would contribute a written article to the discussion. A point he would like to refer to was the question of the propeller. On some machines fitted with Rolls-Royce engines it was not unusual to find when the machine was leaving the ground that the propeller was turning at just about 1,500 r.p.m., and the ground engineers seemed satisfied. The maximum h.p. from the engine was delivered at about 1,900 r.p.m. and it seemed to him that they could get a safer performance on the climb and absence of detonation on the engine with propellers of smaller ranges of speeds. Other difficulties would arise with steel piping for benzol, as steel was susceptible to benzol. The best results had been obtained by lining the steel with lead. Several aspects of installation did not receive enough attention, some of which were electrical. Many makers employed magnetos with a rotary spark-gap instead of a wipe contact with a carbon brush. There one got a static discharge in the line which led to the hand-starting magneto, and any breakdown of the insulation in that line caused a high frequency discharge with consequent risk of fire. The distributors themselves in the magneto were not a gastight fixture and there again one had a weakness in the installation. Steps should be taken as rapidly as possible to do away with the fragile piping between the top of the petrol tank and the engine. It had been demonstrated that fires had been caused through the fracture of that pipe, and yet it was retained and in multiple engine machines it was considerably increased in length.

It is rather remarkable that although an enormous amount of time and money has been expended on the development of the petrol engine, yet no real alteration in the underlying process has yet been made. We still take petrol as the fuel, mix it with air in some form of carburettor, ignite it electrically over a piston and cool the combustion chamber. This process seems as if it is bound to entail the presence and use of a multiplicity of parts difficult to reliably construct and maintain, and in view of aero engine requirements in the future it would almost seem necessary to find some means of changing the underlying process in order that the many difficulties inherent in the present type of engine may be eliminated.

The Chairman stated that an interesting contribution, giving figures of high efficiency obtained with air-cooled cylinders, had been received from Professor Gibson and would appear in the printed discussion.

Captain Hill's analysis of Martlesham results agreed very closely with his own. It did not seem possible to rely upon a fuel consumption during flight of less than 0.6lbs. per b.h.p. hour. This corresponds approximately to a range,

at a cruising speed of about 80 m.p.h., of $28,000/W$ miles per gallon of fuel carried for an average machine. If his recollection were correct, tests at Martlesham on machines ranging from the Sopwith Pup to the big Handley Page machine confirmed this formula. Later, and more heavily loaded, machines might do better. The high fuel consumption in the air was partly due to carburettor design and partly to the fact that economy depended so much on the pilot. If this were taken into account the importance of Mr. Ricardo's experiments on increasing thermal efficiency was greatly enhanced. The use of a "stratified" charge had many advantages for aircraft engines, and Mr. Ricardo seemed to have got a long way on the road to success.

Mr. Rowledge's Paper was full of interesting detail. He (the Chairman) was rather inclined to disagree with him as to the importance of leaving cylinders exposed. It was quite possible that a big gain in efficiency might be obtained by enclosing the engines entirely, except for radiators, and using a different form of body; but more aerodynamic research was needed before such questions could be decided.

Mr. Ricardo, in reply to the discussion, said Commander Cave asked as to the effect of admitting exhaust products upon the ignition. So far as it was possible to see it had no effect. Air had to be ignited there if there was any large power. The ignition timing with stratification in all the diagrams he had shown, whether on lightest or fullest load, was the same. The expansion line was equally vertical at all loads, due to the fact that the combustible part of the charge was in a state of violent turbulence. With producer gas it was only possible to get satisfactory results on stratified charging over a narrow range; with exceedingly rich fuel and very small quantities the problem was very different and much easier. Major Wimperis asked why cooled exhaust gases stopped detonation. He thought it was simply a braking effect which slowed the normal rate of burning, apparently from purely mechanical causes, separating the particles of air and fuel from each other. (The Chairman: "It lowers the maximum temperature." Major Wimperis: "Very little.") Mr. Ricardo: "I don't think that will explain it."

Mr. Rowledge, also replying to the discussion, said he agreed that most of the magneto troubles were mechanical, and he thought if the makers could be convinced that the peacetime requirements were worth their while to supply, they would quickly get good results.

Mr. Chorlton raised the question of the two important considerations—weight and quality. Although in the abstract of the Paper the Author did not refer to this point, the matter is referred to in the description of the Airco 18, and the Author read this part of the Paper, pointing out that in commercial machines where the load per h.p. was fairly high, the effect did not show up so rapidly as in the high performance military machine. When one got down to about 10lbs. per h.p. flying weight, the necessity for saving every ounce of weight of the engine was much greater. In the analysis of weights given, he had included the pilot in the structure weight.

Captain Hill referred to the question of consumption. The figures appeared to him quite good. The Vickers "Vimy" used 14.4 gallons per hour total consumption running considerably throttled. It was only flying 83 miles an hour, although it could fly at 120, so of course the h.p. was low compared with what the engine was capable of. It was a good performance to fly with less than .6 of the full power consumption.

The gravity system of petrol supply is an excellent one and would save trouble, but it is open to objections. Colonel Bristow objected to it on the score of danger from fire and on many machines it would be difficult to fit, as the engine was placed too high for gravity flow to be reliable.

On the motion of the CHAIRMAN a vote of thanks was accorded the Lecturers and Air Commodore BROOKE-POPHAM moved a vote of thanks to the Chairman.

Professor A. H. GIBSON (*communicated*): I would wish to express my appreciation of Mr. Ricardo's very suggestive Paper and to concur regarding the importance of the various lines of research suggested therein.

Regarding the present stage of the art of aero engine design, the best of the modern engines are, as the Author points out, capable of giving thermal efficiencies so near those theoretically possible, that no further appreciable improvement in this respect is possible without some modification of the present cycle. The following results from a number of engines tested by the writer during the past two years, which are the best weak mixture results obtained from these particular engines, show this perhaps even more strikingly than the figures given in column 4 of Table 1 of the Author's Paper.

Engine.	Comp. ratio.	Thermal eff. on I.H.P.	Value of $1-(1/r)^{\cdot 250}$	Value of $1-(1/r)^{\cdot 295}$	Ratio of actual eff. to air cycle eff. with variable sp. heat.
A { 100 x 140 mm 1600 r.p.m.	4·7	·334	321	·367	.91
B { 100 x 140 mm. 2500 r.p.m.	5·1	337	·335	382	.88
C { 5½in. x 6½in. 1650 r.p.m.	5·0	·342	·332	·378	·91
D { 6in. x 8in. 1450 r.p.m.	4·5	·316	·314	·359	.88
E { 5in. x 7in. 1500 r.p.m.	5·3	·329	·342	389	.85

The first four of these engines are air cooled, the last is water cooled. It will be seen that in the air-cooled engines the thermal efficiency is in every case slightly greater than is given by the expression.

Incidentally, it should be noted that in an engine having different compression and expansion ratios, the efficiency depends both on the ratio of compression and expansion and not solely upon the latter, although this is the more important of the two. Thus, in the case instanced by the Author, of an engine having a compression ratio of 4.85 and an expansion ratio of 8.0, the efficiency would be approximately 0.44, as compared with 0.38 with expansion and compression ratios each equal to 4.85, and 0.46 with ratios each equal to 8.0.

The lines of development suggested by the Author refer to

(*a*) The use of a fuel of high toluene value, with a view of enabling the limits of compression ratio to be raised to as high a point as possible.

(*b*) The use of cooled exhaust gas, with the same end in view.

(*c*) Working with a stratified charge.

As regards (*a*) the researches carried out by the Author and other investigations have already had valuable results, and further investigation will probably lead to further developments in this respect. There does not appear, however,

to be much prospect that any mixture suitable for high altitude work will enable a compression ratio greater than about 6.5 to 1 to be attained at full throttle under ground conditions.

Regarding (*b*) the possibilities appear to be much greater. It would be interesting, however, to know whether the reduction of the rate of burning, due to the addition of inert gases, detracts from the possibility of operation at such high speeds as are common in aero engines. Also whether the addition of such gases requires to be kept within very narrow limits in order to ensure satisfactory operation. In the latter case any sticking of the control valves or any sooting up of the supply pipe might readily render the engine unsafe, either through insufficient or too great dilution of the charge.

Regarding (*c*) also the possibilities appear to be great. Here again it would be interesting to know whether the system has been tested at high speeds. The method would appear to be excellently well adapted for use in slow speed engines. It appears somewhat doubtful to what extent the total heat losses to the walls would be reduced, since the differences of temperature throughout the whole mass of working fluid would be considerable, and the temperature of that part of the charge actually burning would probably be little less than in normal operation. There would also appear to be a strong probability that owing to diffusion at the boundaries of the air of dilution and of the combustible mixture, some part of the mixture would be too weak to burn, and that some of the fuel would be lost in this way. This, however, is a point which will depend greatly on the cylinder design, and can only be settled by experiment.

Other lines of development, additional to those suggested by the Author, would also appear to merit attention. Among these may be mentioned the possibility of developing a practical dual combustion cycle, with combustion partly at constant volume and partly at constant pressure. Such a cycle offers certain theoretical advantages,* and should be well adapted for utilising the high flash point having aromatic hydrocarbono derived from kerosene.

Apart from the development or modification of existing cycles, much detail research work can still, with advantage, be done with a view of bringing the performance of the average aero engine into line with the best of its type. The positions of the sparking plugs, the type and reach of the plugs, the arrangement of the induction system and of the inlet and exhaust valves, all affect the performance to an important extent, and their exact effect requires much further investigation.

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* W. J. Walker. Proceedings of the Institution of Mechanical Engineers, December, 1920.

DEVELOPMENT OF GIANT AIRCRAFT IN GERMANY.

SECTION 2.

German Giant Aeroplane Performances.

It is extremely difficult to obtain reliable data concerning the actual performances of German giant aeroplanes, and it will therefore be better for our purposes to confine ourselves to generalities without the use of actual figures, whose reliability may be open to question.

In the first instance as regards "speed," we find within each of the two "A" and "B" type designs, that the speed diminishes as the number of motors increases. That is to say, a *two*-engined "Type A" aeroplane will have a greater speed than a *four*-engined "Type A2" machine, with conditions as regards the horse-power loading and wing loading approximately the same.

Exactly the same rule is distinguishable in the case of the "Type B" machines. In the case of the "Type A" machines this result is obviously to be expected, firstly, on account of the extra head resistance introduced by an increased number of motors when exposed to the wind; and secondly, on account of propeller "interference" and inefficiency.

One has to go more deeply below the surface to locate the reason for this drop in speed where "Type B" machines are concerned. The real reason is however clearly due to increased weight of engine and transmission system, coupled with the approach of structural limitations arising from the too great concentration of "weight." Nevertheless, the speed of the "B type" machines is on the whole higher than their corresponding rivals of the "A type."

Generally speaking, the speed of the *largest* "Type A" machines may be taken as being 130 km. per hour, and in the case of "Type B" machines about 140 km. per hour. In neither case is the speed as high as is desirable for a first class military machine.

As regards climbing capacity, we find that in case of the *largest* machine the "ceiling" is reached in both "A" and "B" types at a height from 6,000 to 7,000 feet. This is again very low, so that we may say that the "performances" of the larger German giants are at first sight very poor. It must, however, be remembered that these machines carried a very high proportion of useful load, and were, by comparison with smaller machines, very heavily loaded. (The bomb load of the standard "Type H" four-engined machines amounted to 3,000 kilograms.)

Range and Duration.

The largest German giants in general use at the close of the war carried under normal conditions about 6½ hours fuel. It must be remembered, however, that the duration of flight could be prolonged very considerably by the addition of extra tanks and the corresponding reductions of the bomb load. So that the maximum duration of these machines (when carrying no bombs) would be nearer twelve hours than six hours. The majority of "Type A" machines were arranged to accommodate extra tanks, which could be rapidly fitted when required.

In the case of "Type B" machines—due to the lower percentage of useful load—the "duration" figures must be taken as being somewhat lower than with the corresponding "Type A" machines.

So far as the maximum figures for "range" are concerned, we may safely say that the ordinary standard German (war) giant had a normal "radius" of about 400 miles, and a maximum possible "radius" of about 800 miles, when flying in still air. In other words, these machines could in still air cover 800 miles in a straight line when carrying their bomb load, or 1,600 miles when carrying no bombs.

When compared to the sensational "record" endurance flights, as for example the trans-Atlantic flights, these figures do not appear to be very good. The figures given, however, correspond to military circumstances as opposed to "competitive" conditions, and the load carried includes a vast quantity of armament gear in addition to the actual bombs, fuel and crew.

We must observe that the above figures correspond to four and six-engined machines, equipped with a total horse-power of between 800 and 1,500. What then would be the effect, if we could, without affecting the total horse-power, reduce the number of engines from four or six to one? Both theory and practice agree in forecasting a higher "performance" and a greater "range." We should lose only in respect of "reliability"; this is a question, however, of which we shall treat elsewhere. It is important to insist that in principle the fewer the number of engines the greater will be the "performance" and the larger the "range." We must remark here that Germany, in endeavouring to prepare a "heavier-than-air" reply to the American declaration of war, commenced to build a giant aeroplane intended to bomb New York (from Europe), and at the same time commenced to experiment with 1,000 h.p. engines with which to equip this machine.

A vast extension of "range" is to be expected from the development of the super-compression motor with its high fuel economy and great efficiency at high altitudes. It is not improbable that from this item alone it will be possible in the very near future to count upon a 30 per cent increase in the "range" of giant aeroplanes.

(d) PERFORMANCE, ETC.

Note.—In relation to a possible advantage accruing from the use of "Thick" wing sections.

During a visit to the Junker factory at Dessau, Professor Junkers, in demonstrating his method of obtaining wind tunnel results, drew attention, while discussing the experimental results of "thick" wing sections, to the fact that the employment of a thick section restricted very considerably the movement of the centre of pressure. Statements of German "Junker" pilots to the effect that the "Junker" was exceptionally steady in bad weather would seem to corroborate this statement.

The point is therefore likely to be of considerable importance in very large machines, which up to date have been notoriously "heavy-handed" in bad weather, not only on account of the increased stability which is the natural sequence of such circumstances, but also on account of the possibility of saving weight in the tail planes and elevators, and in addition as adding to the comfort of the passengers and pilot, or in the case of military machines, insuring a better "bombing platform." This fact also mitigates to some extent the disadvantages of "cantilever wings" in necessitating a relatively large chord, as in ordinary circumstances the greater the "chord" of the planes the more uncomfortable does an aeroplane become in bad weather.

Section (*a*), Crew and Disposition of Defence Armament in the Machine.

As a rule the war crew for German giant machines consisted of two pilots, two mechanics, one navigator, and one machine gunner—making a total of six

men. Of these, the two mechanics were also trained machine-gun operators, and the machine gunner may be regarded as an extra mechanic. The actual composition and numbers of the crews naturally varied slightly in accordance with the individual circumstances of operations or bomb raids.

Actually, so far as war experience goes, we are obliged to rely entirely on information in regard to "Type A" machines only, as none of the "B Type" machines seem to have been in use at the front, and our "C Type" had not yet emerged from the preliminary small-scale stage.

The four-engined and five-engined "Type A" machines carried a formidable armament in machine guns placed as follows:—One in the fore-part of the fuselage, two in the after-part of the fuselage, one of which fired downwards through the fuselage, the other being on top of the fuselage. In addition to this, two other machine guns were carried, one in either engine nacelle. The engine nacelle guns were portable and could be fired either outwards from the engine nacelle itself or from a ring mounting fitted in the top plane immediately above.

This disposition of the guns gives an admirable field of fire, particularly in a backwards direction, since the two top plane mountings in the wings are clear of the tail planes and fuselage.

It is doubtful if this concentration of machine guns was really necessary, but at the same time it is worthy of note, particularly in view of the German "Gotha" casualties at the close of the war from the action of Entente night-flying "Scouts."

As regards the crew of these giant machines, one cannot but be struck with the number adopted when considering also the total horse-power of the machine. At the same time it is difficult to imagine any reduction which would not seriously hamper the efficiency of the whole as a fighting unit. While this matter may appear somewhat trivial, it is in reality of considerable importance, since if six be the minimum number of crew required for a "giant" machine, it is a clear indication of the fact that a "small" giant machine of medium horse-power is not only unlikely but certain to be useless. Indeed, on a rough practical estimate one might confidently affirm that if a machine must carry a crew of six, it must be of at least 1,500 horse-power in order to carry the necessary additional load of bombs and fuel.

The question of crew and defensive armament for giant machines is extremely important in view of the weight involved, which in the case of six men and five machine guns with ammunition totals about 1,500lbs. The formidable total directs us to inquire as to the proportions in weight required, firstly for the pilotage navigation and "running" of the machine itself, secondly for defence purposes.

Obviously if it is possible by careful training to combine the various functions of the crew, a considerable saving in personnel might be effected; on the other hand, it is necessary in this case to study the "endurance" of the crew, since for very long periods at high altitudes it is necessary to provide "reliefs" for essential duties.

A "war" crew must clearly be selected after consideration of the offensive and defensive functions of the machine, and this will impose, therefore, a definite *minimum* limit on the number required. For purely offensive bombing purposes two men would be sufficient to work any machine, that is to say, one pilot and "one bomb-dropper"—any other members of the crew so far as the actual bomb-dropping is concerned would be unemployed. If then, two pilots are selected for a giant machine—both being, in addition, trained as "observers," navigators and bomb-droppers—these two men are sufficient crew to carry out all the necessary duties in connection with navigation, observation, and attack. It remains to decide upon the number of men required for "defensive" purposes and for duty as mechanics in connection with the engines, etc. These mechanics trained in addition as machine gunners should be able to fulfil all such functions in any

machine with not more than four motors. It is even possible that this number is too high except for very long range flights; in any case it is difficult to justify the inclusion of more than five properly-trained men in any giant machine so far built.

It is quite clear, however, that the crews of "giant" machines must be thoroughly trained and able to undertake a far larger range of duties than is required of aeroplane personnel employed on ordinary small machines.

Section (*b*), Bombs, Armament.

It is unnecessary to refer at length to the question of bomb armament, or any special bomb-dropping mechanism. The German giant machines show, however, a sharp divergence from Entente practice both in the quantity of bombs carried and in the method of carrying them.

The main offensive armament of German giants consisted of two or three very large bombs. A certain number of very small bombs were also carried, but these are of very secondary importance as regards the main functions of the machine.

Whatever may be the military advantage or disadvantage of concentrating the total weight of explosives in a very small number of bombs, there is no doubt that the adoption of this principle facilitates very considerably the arrangements for the storage and the carrying of the "bomb load." Not only is the weight of the bomb-carriers, release gears, etc., very much reduced by having only two or three bombs instead of ten or twelve, but the space required for storage is also very much smaller.

Whereas it is necessary when carrying a large number of bombs that the designer make careful and elaborate provision for their storage—perhaps to the disadvantage of some other requirement—in the case of two of these large bombs, the problem is very much simpler. Added to this it is, generally speaking, quite easy to arrange for the carriage of two or three bombs in a horizontal position, while in the case of a large number of bombs it is commonly necessary to adopt a "vertical" method of storage—with all the attendant disadvantages.

In respect of bomb-carrying equipment and storage, there is a good deal to be said in favour of the German practice, a circumstance which must be reflected in either a saving in weight or a saving in head resistance, as also in a lesser complication.

Section (*c*), "Maintenance."

The German giant aeroplanes, which, as we pointed out in the introduction, were primarily intended for strategic purposes, possessed, in consequence, several unsatisfactory and undesirable features. Generally speaking, the practical aspects of "maintenance" were almost totally disregarded. The time required to effect the changing of an engine is given as five to three days, a period which must be regarded as insupportably long. No special facilities exist for the rapid changing of wings, under-carriages, wheels, etc. The larger machines, particularly, may be said to be quite exceptionally impracticable as regards the elementary military requirements in relation to what we may refer to generally as "maintenance in the field."

It is to some extent true that these same faults are to be found in almost all giant machines, whether of German or Allied origin. In the case of German machines it may, however, be confidently asserted that the lack of attention to these important details very largely prejudiced the use and value of all existing giant machines.

(4) POWER PLANT AND INSTALLATIONS.

Section *(a)*, General Arrangement.

The horse-power required for giant machines being very much in excess of anything which can be obtained from a single engine unit, the designer is forced to adopt some arrangement which will accommodate a sufficient *number* of motors to provide the required total horse-power.

The problem of motor arrangement in giant machines may almost be said to be the principal consideration of the designer, who up to now has been confronted with the problem of how best to dispose the number of separate engine units which together make up the total power plant.

In so far as the range of horse-power obtainable from a single motor permits, it is obvious that there is nothing to be gained, except " reliability," from the adoption of more than a definite minimum number of engines. When, therefore, very large total horse-powers are required, the maximum horse-power of the individual motor is of very great importance. It is as well to recall here, as already noted in the introduction, that during the war Germany's designers had at their disposal only comparatively low-powered six-cylinder engines. This fact, then, is destined to have a very important bearing on engine arrangement and aeroplane design. (We have previously remarked that the revelopment of the V-type motor took place too late in Germany to be of service during the war.)

It will, perhaps, be best to consider first the question of engine arrangement as applicable in general to the three " Type " designs which we have discerned in German giant aircraft, since, apart from other details, it is obvious that the question of motor arrangement must exercise a profound influence on each design, and that all such arrangements must necessarily be dependent on the unit horse-power of the individual motor. For the German giant machine, up to the close of the war, the maximum horse-power available in a single unit did not exceed 300, and, generally speaking, may be taken at even less than this figure.

Motor Arrangement in " Type A " Machines.—Refer to Figs. (*a*) to (*g*) for " Type A."

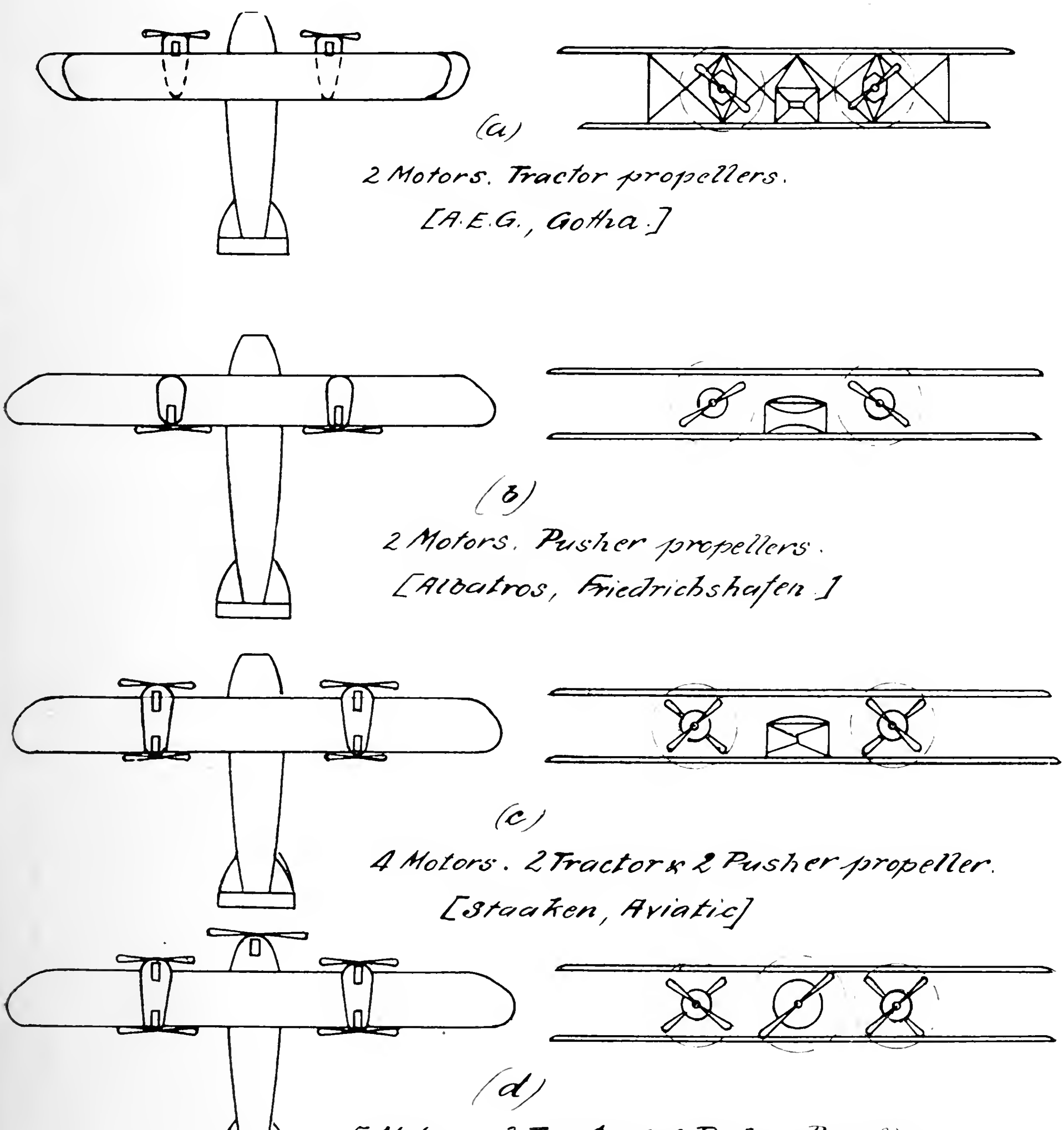
The sketch diagrams (*a*) and (*b*) represent the first stages in the development of the giant " Type A " machine. These designs are well-known, and there is no doubt that this two-motor arrangement is a simple and satisfactory compromise *within* the limits of horse-power which the use of two motors permits. In the case of Germany this limit was a low one, and may be put at a maximum of 600 h.p. It follows that other arrangements had naturally to be adopted in order to permit designs to increase still further the total horse-power (and hence the useful load).

The next step in development is illustrated in Fig. (*c*); it is a combination of Figs. (*a*) and (*b*), and has the advantage that it permits of the total horse-power being doubled with only a slight increase in head resistance. This arrangement has, however, the obvious disadvantage that the rear propellers are working in the " slip-stream " of the front propellers, and are consequently inefficient. The compromise is, nevertheless, in many respects a good one, since it introduces no unnecessary complications. The same simple method of construction can be used, and the arrangement retains the good points of the " Type A " weight distribution. Moreover, in this particular case the engine nacelles become sufficiently " roomy " to accommodate a mechanic between the two engines, and it is possible, therefore, to claim that the engines are accessible during flight.

Fig. (*d*) illustrates the next step in the effort to apply still more horse-power to a single machine. In his case, however, we find that the five-engine design (Fig. (*d*)) *preceded* the construction of the latest type four-engined (Fig. (*g*)) machine. This circumstance is yet another indication of the unfortunate circumstances in which German designers found themselves in regard to the available horse-power from a single motor unit. The point is one of peculiar interest, as it shows that the five-engined design was abandoned in favour of the four-engined

system *so soon* as a slightly more powerful motor made its appearance, and thus allowed of a four-engined group to develop more power than had previously been available with *five* motors. It is only necessary, however, to remark that the presence of the fifth motor (Fig. (*d*)) was also undesirable from a military point of view as interfering with the " view " of pilot and passenger.

Sketch diagrams illustrating the Engine Arrangement in "Type A" machines.

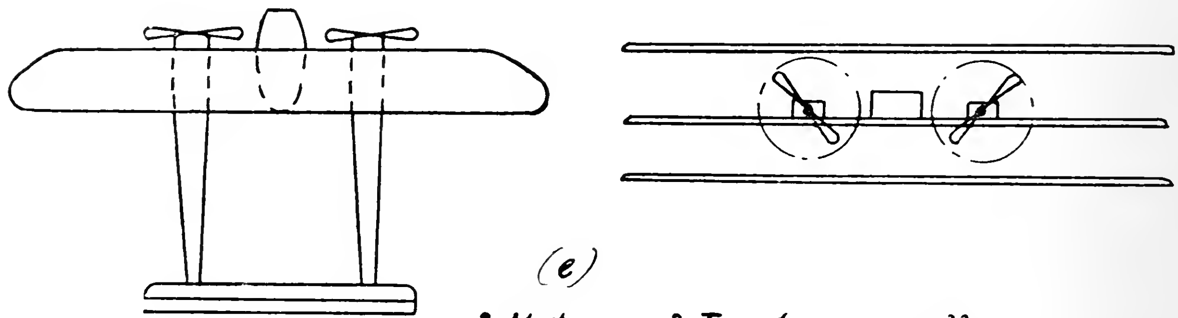


Figs. (*e*) and (*f*) illustrate yet another variation of motor arrangement within the " Type A " designs. This system, originally developed by Caproni, has never been very satisfactory, and is not adapted to the employment of more than three motors. The design, therefore, seeing that the development of giant machines has

been contingent on the available *total* horse-power, could only serve as a "stop-gap," and is incapable of development.

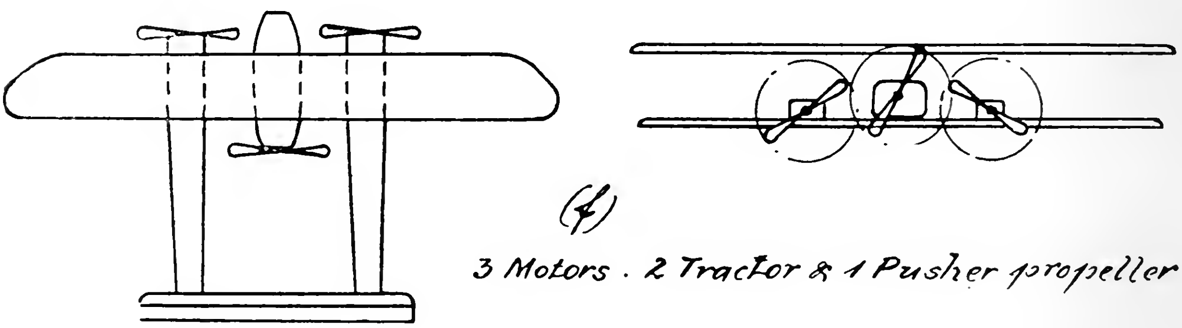
Fig. (*g*) illustrates yet another variation of motor disposition. This design, originally intended for aeroplanes, has only been developed in seaplanes, and is for our immediate purpose of no great consequence. The motor arrangement is identical with that of the previous four-engined types, and the disposition differs only in relation to the planes.

In none of the foregoing arrangements is there any difficulty, so far as the



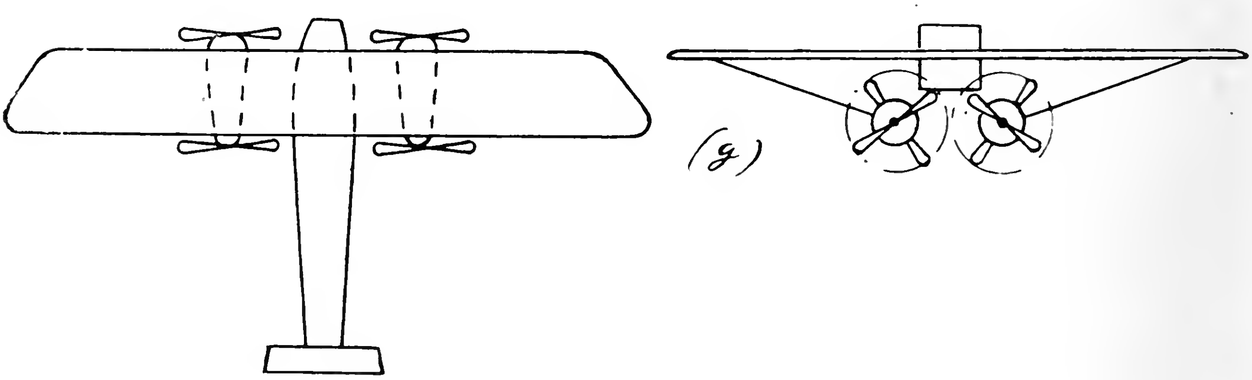
(e)

2 Motors. 2 Tractor propeller.



(f)

3 Motors. 2 Tractor & 1 Pusher propeller.



(g)

motors themselves are concerned, in the matter of engine installation. Neither does the adoption of any of these motor dispositions introduce special complications or difficulties in the design or construction of engine beams, tanks, controls, connection, etc. From this point of view, then, the question of arrangement, design and construction of the "Type A" power plant installation is simple and satisfactory.

We have shown in the previous chapter how German designers were driven to abandon "Type A" designs for "Type B" in an endeavour to increase efficiency and at the same time to augment the available horse-power. It must now be pointed out that the question of engine arrangement (which was primarily

responsible for this departure) was also contingent on the question of *propeller* arrangement; these two points are indeed inseparable. In the case of the land aeroplane the designer has a wide choice of propeller positions, but on the other hand the seaplane designer has to give considerably more attention to this matter on account of the danger to propellers from spray and waves. Certain variations in motor disposition are to be expected, then, as between the giant aeroplane and seaplane. This point is of no particular importance for our purpose, but is mentioned in order that any novel arrangement in seaplane motor positions may not serve to distract one from the main circumstances.

The question of "gearing" will be treated later, in Section (*b*). It will suffice for the moment to say that in the case of "Type A" designs the introduction of gearing may be regarded as an accessory circumstance which in no way affects the actual design or execution of the machine.

General Remarks on "Type A" Engines and Installation.

All through the "Type A" designs a general simplicity in the engine installation is to be remarked. There is no unnecessary complication, the various component parts of the whole power transmission are fairly widely separated and readily accessible when on the ground, if not in flight. The whole of the fuselage is left clear for crew, armament and *fuel*.

Engine or Motor Arrangement in "Type B" Machines.—Refer to Figs. (*a*), (*b*), (*c*) and (*d*) for "Type B."

In the case of "Type B" designs, the sequence of development is again fairly clear. The first arrangement to appear in a concrete form is illustrated in Fig. (*b*) (four engines with four wing propellers). This design was shortly followed by the Fig. (*c*) disposition, which is indeed the same arrangement, except that six engines are used instead of four.

Fig. (*d*) illustrates a still more recent development. As before, the sequence of production has a certain significance, and must not be overlooked. Fig. (*a*) represents a late development of the (*b*) and (*c*) arrangement, which was apparently never seriously taken up, but probably represents an attempt at high speed and long endurance. The machine is, of course, considerably smaller than its prototypes.

To revert to the Fig. (*b*) four-motor, four-propeller design, we find here the first attempt to realise "accessibility" for the motors, and in conjunction with this an improved "performance," due to reduced head resistance. It is also necessary to remark that with this motor arrangement the designer is able, by utilising suitable transmission gears, to so dispose his propellers that their disc areas do not overlap. This feature is, of course, a distinct advantage over the back-to-back motor disposition which we find in the four-engined "Type A" machines.

So far, then, as the general efficiency of the propelling units is concerned, this arrangement should give a very much higher figure of efficiency than has hitherto been possible. If, then, the gearing and transmission systems prove to be satisfactory, the general design and disposition of the power plant installation on these lines would appear to be almost ideal. We are not, however, for the present concerned with the gearing, which introduces its own special problems. It must, however, be remarked that in spite of its many apparent advantages, the actual and practical installation of the motors in a necessarily somewhat confined space, is not altogether satisfactory. Indeed the whole installation becomes so cramped that "accessibility" becomes, perhaps, a more theoretical than practical advantage. Nevertheless, it is impossible to deny a certain advantage in regard to "maintenance," protection from weather, etc., which this system

possesses. It is quite obvious, however, that the adoption of so much gearing and special transmission shafting introduces very real mechanical difficulties, and calls for far more technical skill, even in the mere routine of " maintenance," than in any other type yet considered. This gearing, moreover, adds considerably to the weight of the power units; but as we have already remarked, this must be opposed by the possibility of a largely increased " efficiency."

Demands for a further increase of power in the case of this design are met (Fig. (*c*)) by the addition of another two motors coupled up through the same system of gearing, and an identical propeller disposition. The only real difference, therefore, between types Fig. (*b*) and Fig. (*c*) is in the detail arrangement of gears and transmission. The whole installation becomes, however, still more complicated, and the need for expert mechanics to operate the necessary clutches and other accessories is clearly apparent.

Fig. (*d*) illustrates another variation of the same arrangement, differing principally in the matter of propeller disposition, and possibly offering, on account of the comparative simplicity of the gearing and transmission, a more practical solution of the problem. The relative efficiency of the single and four-propeller arrangement is a matter of simple calculation. In any case a considerable reduction in the weight of gearing and transmission shafting is to be reckoned on. At the same time the practical military disadvantages of the large tractor propeller—in front of a fuselage already too large to permit of good observation—are very real.

The installation of the motors and gears is in this case again very cramped, though the advantage of " accessibility " and general protection from weather remains.

General Remarks on the Engine Installation of " Type B " Machines.

In considering the engine installation of these various " Type B " designs, it is impossible to avoid being unfavourably impressed by the complications and congestion which the massing together of the motors in the fuselage entails. It is difficult at first sight to account for this feature in what is fundamentally a quite simple arrangement. The effect, however, is not surprising when it is remembered that in addition to the motors themselves it is necessary to find accommodation in the fuselage for the crew, transmission shafts and gearing, with the necessary clutches, armament, bombs and *fuel*. In addition to which must be reckoned the further complication of concentrated engine controls, fuel piping, etc., etc. Moreover, it is impossible to dispense with any of these items, and even the petrol tanks cannot be excluded from the fuselage, since there is no room *inside* the wings, and to place them *between* the wings would only set up additional passive head resistance (at the suppression of which the design is aimed).

The engine bearers, which must in any case be specially strengthened to take the concentrated weights of the engines and gears, have to be made even stronger than one might anticipate, owing to the well-known fact that a number of separate engines running on the same bearers or platform demand a far greater degree of rigidity than is normally required for one engine.

All these factors conspire, therefore, to multiply complications and with this to add very considerably to the structural weight of the fuselage. So that even if the increased efficiency obtainable from the choice of propeller disposition, propeller revolutions, and the suppression of head resistance, is more than sufficient to counterbalance the weight of gearing and transmission shafts, there is still a very considerable additional fuselage structure weight to be compensated for.

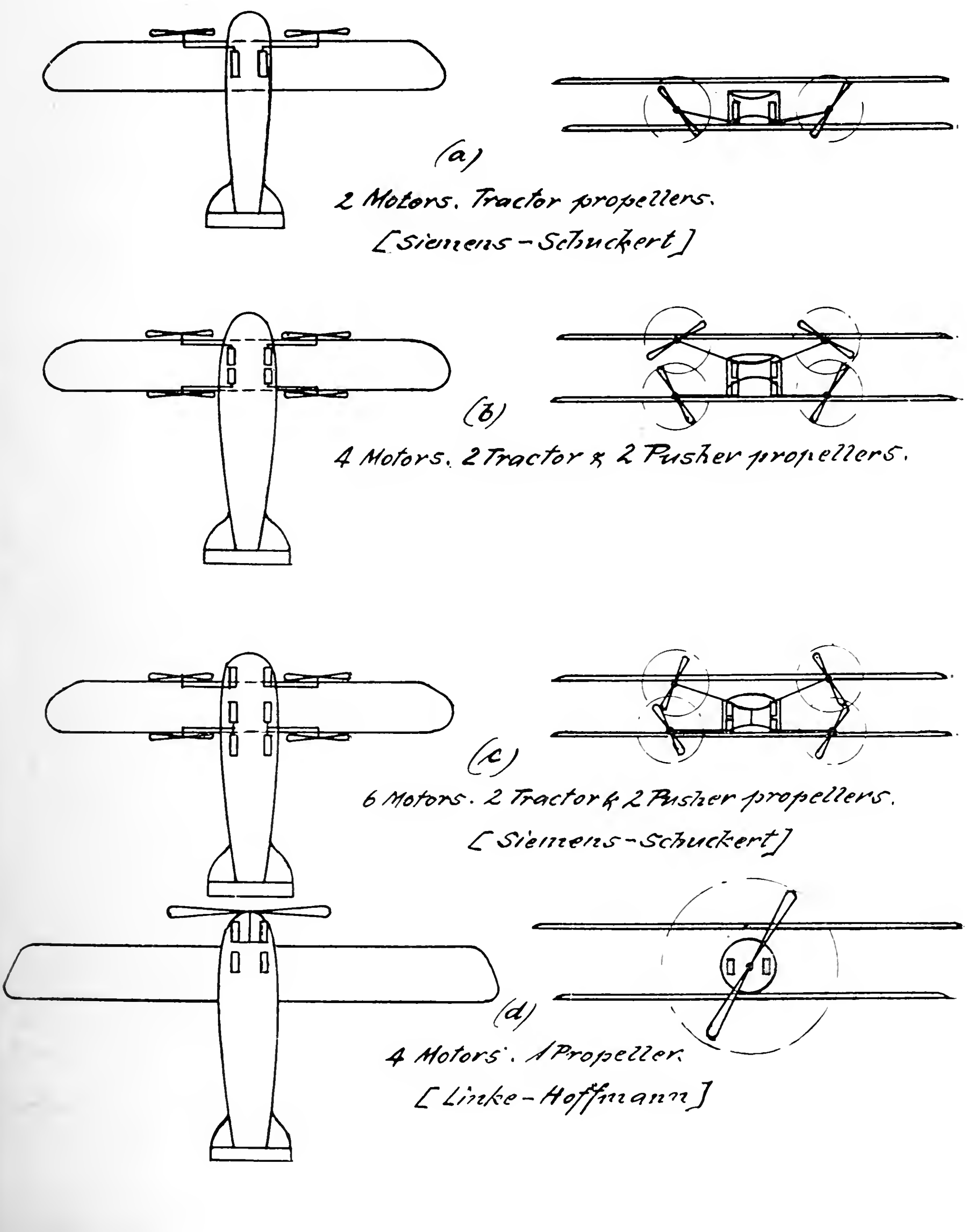
Moreover, the possibility of employing the motor arrangements in the " Type B " designs is entirely dependent on the provision of suitable and satisfactory

gearing; and the motors themselves must in this case take second place in importance to the gears and transmission.

In practice, the installation of these multi-engined groups, their gears, clutches and shafting, is by no means a simple matter. The mechanical difficulties are considerable and the arrangement has the further disadvantage of complication within a confined space. In addition to which the mechanics or engineers carried in the machine must be very highly skilled.

④ Power-plant and installation. Section (A)

Sketch Diagrams illustrating the Engine Arrangement in "Type B" machines.



Arrangement of Power Plant in "Type C" Design.—See Figs. (*a*), (*b*), for "Type C" designs.

The installation of the motor in the single-engined "Type C" machine, illustrated in Fig. (*a*), is so simple as to need no comment. It is only necessary to draw attention to the disposition of the fuel tanks of which we shall have more to say in Section (C) of this same chapter.

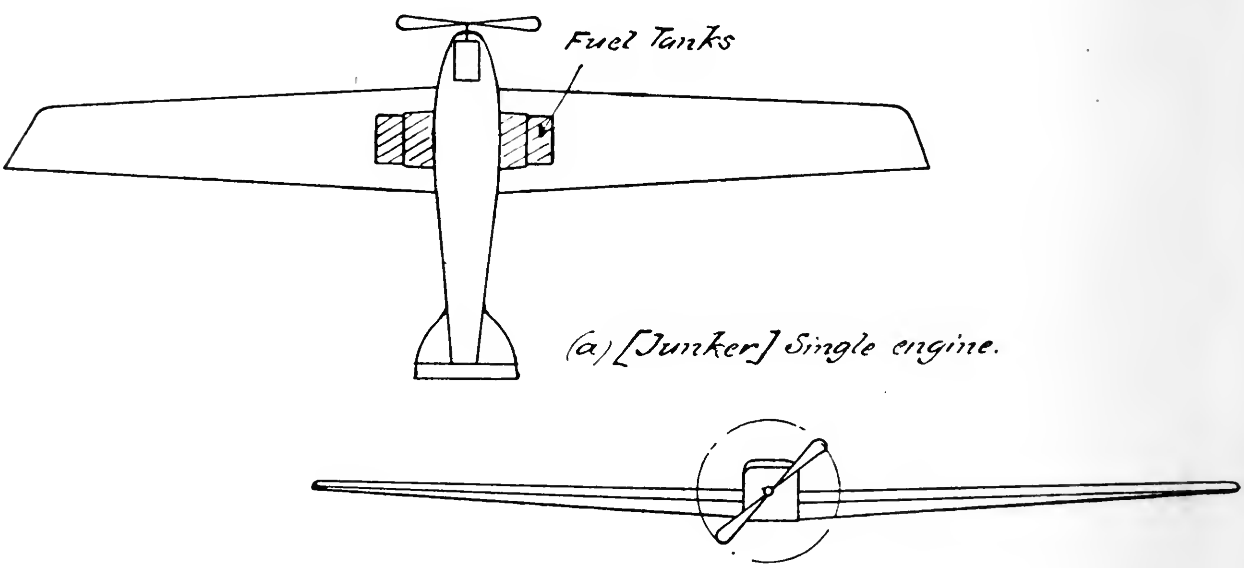
Fig. (*b*) illustrates an imaginary development—which is already conceived in the mind of Professor Junkers—and to which we shall have occasion to refer in our conclusions.

In both these cases we note a complete simplicity in engine installation, comparable with that existing in the "Type A" designs.

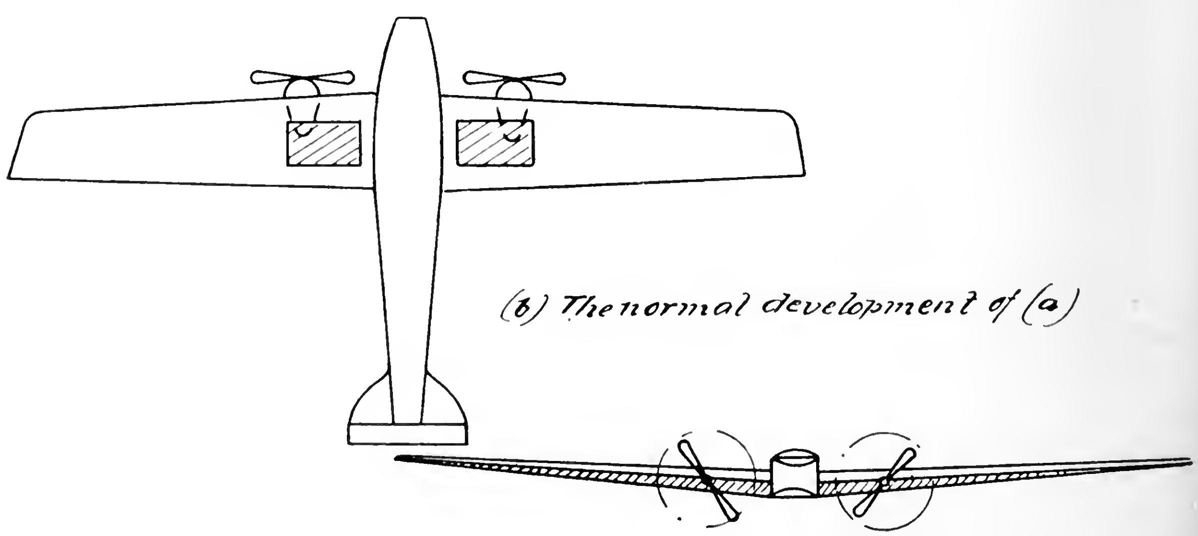
Section (*b*), Gears and Gear Drives.

As is well known, an air propeller develops its maximum efficiency at about

Sketch Diagram illustrating Engine Arrangement in "Type C" machine



(a) [Junker] Single engine.


(b) The normal development of (a)

900 revolutions per minute. This speed is considerably less than the normal crankshaft revolutions of an aeroplane motor, and it is possible, therefore, to increase the efficiency of the propelling units by introducing gearing between the crankshaft and the propeller. Hence the reason for the adoption of "reduction gearing."

In Entente countries the development of the high speed V-type motor was accompanied in the majority of cases by the introduction within the engine unit itself of a reduction gear. In every case the reduction gear formed a definite part of the engine, and was incorporated in the same lubrication system, etc.

In Germany, however, owing to the fact that the standard six-cylinder stationary motor had a much lower crankshaft speed than the Entente V-type motor, the necessity for reduction gears was very much less marked, and indeed quite unnecessary except for the comparatively slow giant machines. We find, therefore, that while the existing German giant machines are fitted with reduction gears, the gears themselves are separate units in regard to the motors. This circumstance entails the use of larger and stronger engine bearers than would otherwise be necessary, besides introducing other complications such as the provision of special lubricating systems.

The main fact which we must bear in mind, however, is that the "*reduction*" gears found in German giant machines are fundamentally the same development as we are already acquainted with in the Entente V-type motors. In the case of the German giant machines the actual ratio of reduction is, of course, calculated for the particular machine to which it is designed, whereas in the case of Entente "engine gears" the gear ratio is a compromise.

It has been necessary to make this general comparison before considering the actual arrangement of the German gear and gear drives, in order that we shall not be misled into thinking that these gears are a novel departure in aeroplane practice. Actually the system is well known and extensively used in Entente countries, where, however, the whole arrangement is enormously simplified (if not so efficient), and where we require no additional lubricating systems and no oil-cooling radiators. It is important, before proceeding further with this particular inquiry, to remember that the "reduction gears," though they may be combined with gear-driven transmission systems, must be considered separately and quite apart from the transmission systems which we shall find in the "Type B" machines.

Gears in "Type A" Machines.

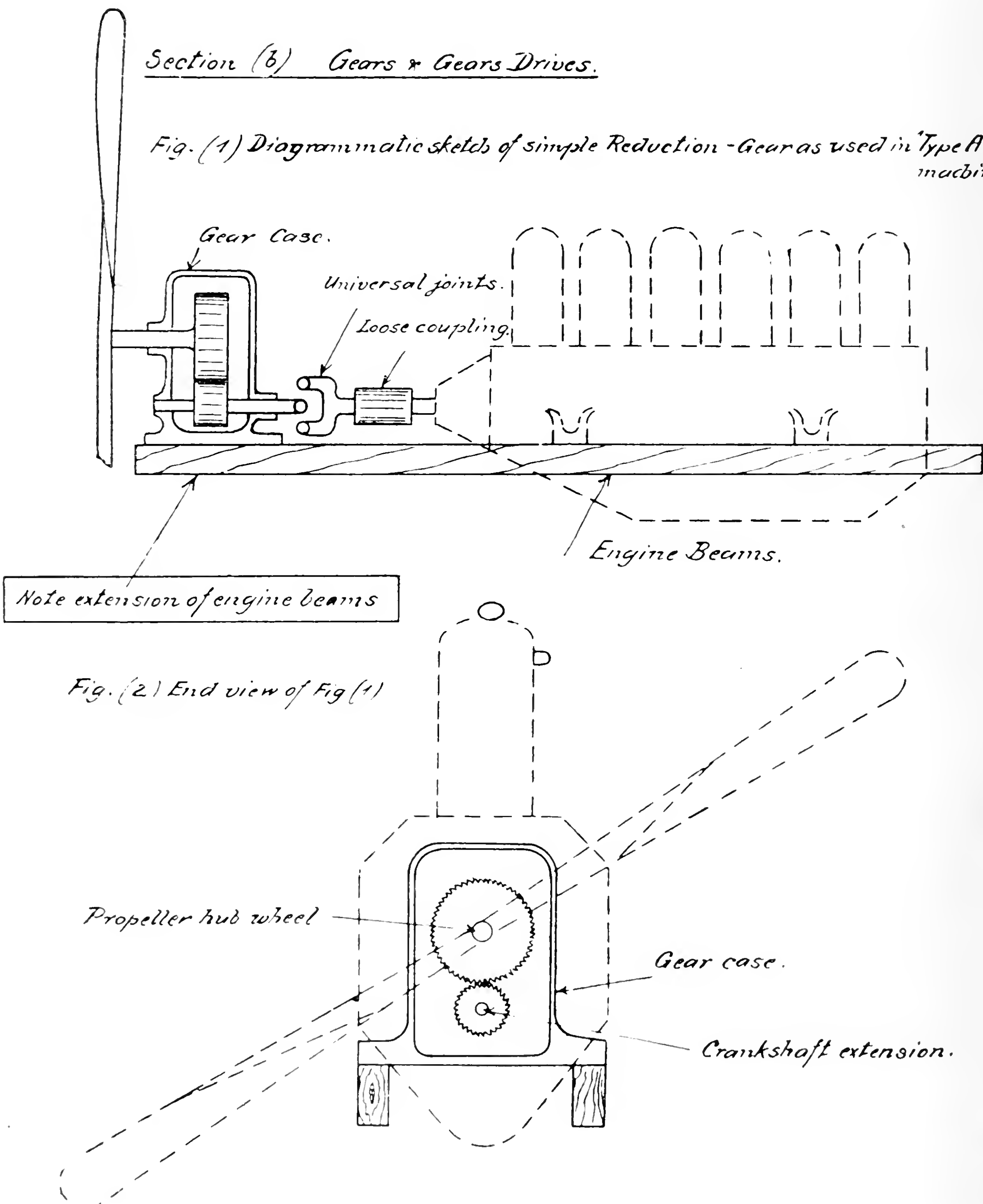
Figs. 1 and 2 illustrate the general arrangement of the type of gear in use on the "Type A" giant machines. The arrangement, as can be seen at a glance, is quite simple, but involves the employment of much longer and heavier engine bearers than would normally be required, and further necessitates the fitting of a universal joint and loose coupling between engine and gear box. In addition to this the gear boxes require a special lubricating system with their own oil-cooling radiators, oil reservoirs, "sight" thermometers, etc. All these details are redundant to the ordinary reduction gear arrangement as fitted in the Entente V-type motors.

As we have already remarked in a previous paragraph, the great advantage of this system is that the reduction gears are specially designed for each individual machine. Naturally, where large horse-powers are concerned, any increase in the propeller efficiency, due to a careful choice of propeller revolutions, must result in a very large gain in useful load. Indeed, a gain of from 10 to 15 per cent. may be expected from the use of carefully chosen gearing over results with a direct driver propeller. Undoubtedly the "Type A" giant German machines owe a great deal of their success to the selection of suitable gearing. It should be added

that the use of these gears, although attended by success, has not been entirely free from small practical difficulties.

Typical Gears and Gear Drivers in "Type B" Machines.—Refer to Figs. 3, 4 and 5.

The gears and transmission systems with their necessary bevel drives serve the dual function of, firstly, acting as "reduction gears" in order to transform



the engine crankshaft revolutions to a suitable propeller speed; and secondly, of transmitting the necessary power from the engines in the fuselage to the propeller itself. As for each propeller, a minimum of two bevel drives are necessary (one

at the engine and one at the propeller shaft), the reduction in the speed of revolution can be made either gradually or in a single train of gear wheels. As a rule it is more convenient to do this gradually by using the bevel drives as " reduction gears " also.

Figs. 3 and 4 illustrate a typical arrangement of gear drive in a " Type B " machine. It is not necessary to investigate the details of the gear box construction or mountings. It is sufficient to say that the gear box itself is principally a " power distributor " which is also arranged to contain one of the necessary bevel drives and to act as " reduction gear."

Reference to Fig. 4, which outlines the arrangement of a six-engined, four-propeller group, will show that besides the six engines the machinery or mechanical plant includes four gear boxes (bevel type), four (propeller) bevel drives, fourteen universal joints and six clutches, in addition to which there is a considerable quantity of shafting. With this elaborate equipment of mechanical plant, one secures, however, the following advantages. Any one motor can be de-clutched and isolated for purposes of repair or if not required. The transmission shafting can be arranged as required to drive the propellers in positions such that their " disc " areas do not overlap. The propeller revolutions can be arranged for maximum efficiency.

As to whether or not the advantages, from a mechanical point of view, are sufficient to counterbalance the very considerable complications which such gearing entails is a matter open to the gravest doubt. It is certain that so far as German experience goes the results obtained have not been entirely successful. The design of the mechanical parts is difficult, the extra weight involved is considerable, and the work of maintenance and adjustment both intricate and delicate.

In effect, from a practical and particularly from a military point of view, complication of this description is best avoided. In any case it is only justifiable if the advantages to be gained are of a more substantial character than is traceable in the machines we have under review.

Gears and Transmission Systems in " Type B " Machines.

Fig. 5 illustrates the gear drive arrangement as fitted to the single propeller " B type " giant (see Fig. (*d*), aeroplane types), as in the other examples of the same type we find a similar complication, though in this particular case the general " lay out " of the gearing and clutches is at first sight slightly more simple.

In practice the congestion and complication which distinguish all these arrangements is clearly apparent and the same difficulties with the engine bearers and gear box details are to be found.

The first set of gears to be tried have not given satisfaction. Nevertheless, it is possible that a reliable gear of this type could be evolved with very little further experiment. In any case the whole arrangement, so far as mechanical difficulties are concerned, is both superior to and simpler than the gearing and transmission system when the propellers are in the wings.

General Remarks on Engine Arrangement in " Giant " Machines.

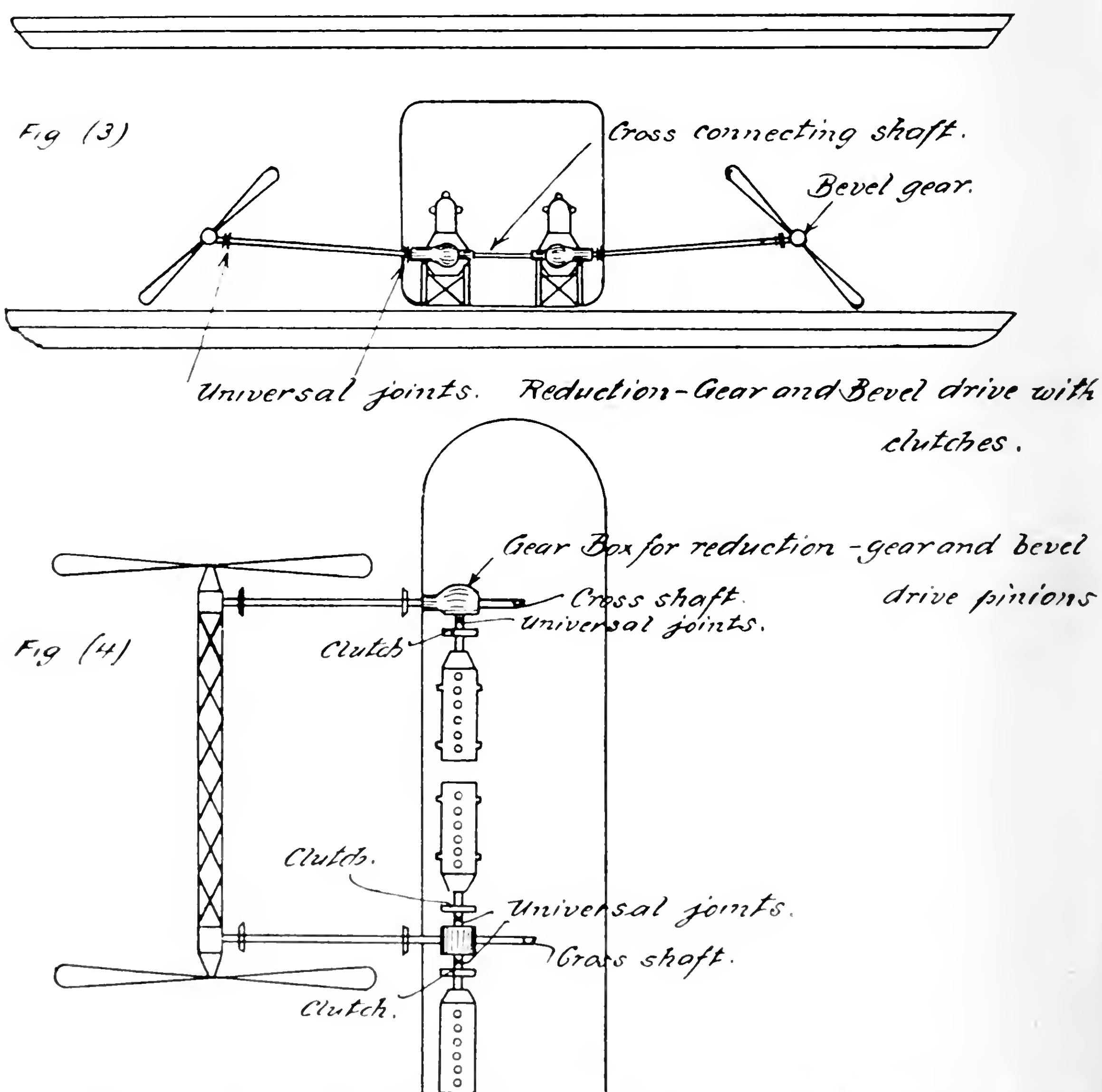
As regards the future trend of events in relation to " engine arrangement," we distinguish three separate and vital factors which must inevitably govern all other considerations: (*a*) Within limits which cannot yet be defined, the best military " giant " machine will undoubtedly require the maximum possible total horse-power. (*b*) The total horse-power of a giant machine should not be made up of a large number of separate engine units. (*c*) Maximum possible horse-power in a single engine unit is essential to success in giant aircraft.

German experience has clearly shown, as indeed was only to be expected, that complication is perhaps the worst enemy of practical efficiency.

It is inconceivable that the German six-engined "Type B" machines could have been designed or built, if it had been possible to obtain the same total horse-power with a lesser number of motors. The presence of six motors in a single machine is traceable to the low unit horse-power of the available German aeroplane engines, and must be considered as accidental or incidental to considerations of "reliability."

Nevertheless, there is no question that larger and more powerful engine units will most probably assure the temporary continuancy of not only "Type A"

Typical 'Type B' machine, Gears and Transmission System.

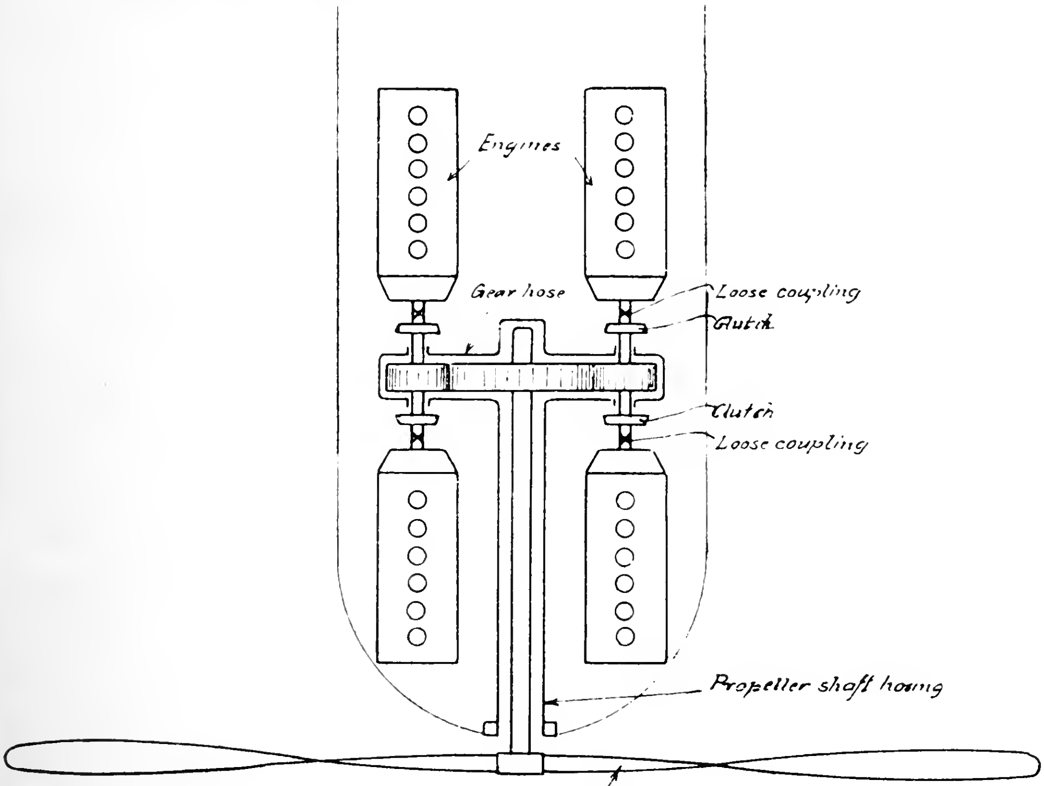


Sketch showing general arrangement of Gears, Gear-drive, clutches etc for in "Type B" six-engined Giant.

but possibly also "Type B" machines. This is indeed certain to be the case when we consider that not only will larger and more powerful engine units permit of the building of larger "giant" machines, but will also allow us to carry more load in a smaller machine. In this way, were it possible to obtain double the horse-power from a single engine than is now the case, one would undoubtedly revert to the twin-engine designs as a preliminary step before again employing a larger number of motors. It is in fact certain that should engine development continue—as there is reason to suppose it will—and should a single engine of 1,000 or 1,500 h.p. become available, then we may rely upon obtaining a better performance with a two-engine design of whatever type than is at present possible with four or six motors. Such a machine would moreover be simpler in every way than the larger giants of to-day, and in consequence of a far greater military value.

Reduction gears & Gear drives in "Type B" machines.

Fig. (5) — diagrammatic sketch of gearing & Drive for 4 engined single propeller Type B giant, (see fig (d) for "Type B" aeroplanes) [Linke-Hoffmann]



It may be objected that such a proposal would sacrifice such "reliability" as the present day designers may claim. The value of this "reliability" in relation to military wants must first of all be examined. If we assume, as indeed must be the case, that giant "military" aircraft leave the ground *when carrying their war load*, with a certain definite "speed of climb," we get some indication of the relative horse-power available in excess of that required for "flying level." To assure *absolute* "reliability," then one must so arrange the power plant that no ordinary accident or circumstance can rob the machine of more power than is required for "climbing" only. With the present state of development in aeroplane motors this cannot be said to be within the realms of possibility, even

if the total horse-power be subdivided amongst several motors. A partial reliability can however be obtained by a sub-division of the power plant, and this is present to a greater or lesser degree in the various examples of German giant aeroplanes.

It is already quite clear that the smaller the number of motors—and consequently the less the complication—so much the better from a purely military point of view. What then is the best compromise, in regard to the selection of the number of motors to be fitted? Efficiency points to the minimum possible numbers required to supply the necessary horse-power. "Reliability" demands the maximum sub-division of the power plant. Military requirements embrace, efficiency, "reliability" and simplicity. The choice must in consequence depend primarily on the military requirements, which in themselves demand a compromise. It remains to decide on the smallest maximum number of motors which such "reliability" as we are justified in demanding from military machines should dictate.

Obviously there is no possible object in demanding a greater sub-division of the power plant than would allow of the machine under any ordinary circumstances of average mechanical failure from returning safely to its base. In a military machine this means that no average mechanical failure would prevent the machine from returning (at a necessarily reduced speed) over a distance representing its maximum radius of action, without its bombs and without unnecessary fuel. Such circumstances would allow of the saving of the machine and also the crew under any and every circumstance, at the trifling cost of jettisoning both bombs and surplus fuel. Briefly, a military giant machine should be able to fly with approximately half its fuel load and with no bombs when under reduced power resulting from the worst possible circumstance of normal mechanical derangement. In a giant military aeroplane the necessary sub-division of the power plant under these conditions is happily comparatively small.

Under no circumstances are designers justified in departing from this criterion of a least maximum number of motors, except where it is impossible to obtain the required total horse-power without exceeding the least maximum desirable number of separate motors. In any case, as we have elsewhere remarked, *real* "reliability" is not to be sought in the number of separate motors, but in the improvement of the individual aeroplane motor itself.

Propeller Arrangement.

Perhaps the greatest potential advantage of the "gear and shaft drive" transmission system lies in the range of choice as to propeller "arrangement," irrespective of the placing of the engine. This particular feature may be of value either from a structural point of view or on account of military requirement in connection of "arcs of fire" for guns.

It is doubtful if in practice either of these advantages will be realised without a correspondingly heavy sacrifice in some other direction. In any case existing German "shaft drive" designs cannot be said to confer any military advantage to examples of machines so fitted; neither has the introduction of shaft drives facilitated or improved construction.

As regards the general arrangement of propeller positions and numbers of propellers in giant machines, there is but little to remark on, except in the case of the "Type B" machines.

The number of engines has in the majority of cases been the deciding factor in the selection of the number of propellers, irrespective of the possibilities of variation which the use of "shaft drives" permit of in all the "Type B" machines—not excepting the case of the most modern engined, single propeller design—the number of propellers has been decided by convenience in the matter of providing shaft transmission.

In effect the whole problem has up to the present been governed by the circumstances in relation to the individual aeroplane engine. Its ultimate improvement is dependent—as indeed is the whole future of the giant machine—on the development of the aeroplane motor, which in time must ultimately decide the number of motors to be fitted in a single machine.

While the disposition of the propellers in multi-engined giants is a factor of considerable importance in relation to efficiency, experience has shown that the distribution of the individual propeller centres away from the "centre of thrust" of the machine is attended by many disadvantages. This is particularly the case when the individual propeller centres are not situated (as in some of the "Type B" machines) on the same horizontal plane as the "centre of thrust." In this case the handling of the machine, particularly when landing, becomes much more difficult, while any variation in the power of an individual motor must be compensated for by both the longitudinal and directional controls.

Section (*c*), **Fuel Storage.**

There is nothing very important to remark concerning the detail arrangements for storing fuel in German giant machines except that as a general rule a large number of small tanks are fitted, as distinct from one large tank with many sub-divisions. Also the weight of the tanks is, generally speaking, proportionately very much less than in Allied countries, because in the majority of cases aluminium is employed instead of tinfoil or brass. These are, however, unimportant details.

It is extremely important for our purpose that the *disposition* of the fuel tanks, as affecting the weight distribution in the machine, should be carefully considered. More especially, as the better the machine, the greater will be the proportion of fuel weight. (It is true that this question is dependent on the proportion of *useful* load allocated to military load, but at the same time a long *range* necessitates a high proportion of the same useful load being allotted to fuel weight.)

It is necessary to consider, therefore, what influence on the general design of giant machines the question of fuel storage actually has. If we consider the weight of the power plant (motors, propellers, etc.) and the weight of the fuel (and tanks) as two separate portions of a single "disposable" weight, then it is quite clear that since neither of the two portions can be dispensed with, the *disposition* of the one must bear a distinct influence on the disposition of the other, if a satisfactory weight distribution is to be maintained. And as these "weights" possess a certain irreducible "bulk," it is clearly not possible on account of head resistance to distribute them haphazard in the machine.

As weight distribution has a direct bearing on the construction, and particularly on the maximum limits of construction, it is obvious that a certain satisfactory medium must exist between the ideal but impracticable limit of equally distributed weight all along the wings and the equally unsatisfactory concentration of weights in the centre of the machine. Herein lies the whole importance of this question of fuel distribution, since apart from head resistance the fuel is the most easily disposable weight portion in the whole machine.

"Type A" designs, whose distinguishing feature is the distribution of motors in the wings, naturally have their fuel tanks in the central fuselage where there is ample room and where—as the fuselage is an essential part of the machine—they create no extra head resistance.

In "Type B" (engines in the centre) the fuel tanks are still to be found in the fuselage; but in this case their presence is very undesirable, firstly, on account of the lack of space and consequent complication; secondly, because the weights are already too centralised.

"Type C" designs (cantilever wings) show the first realisation of this fuel difficulty. Professor Junker places his tanks *inside* the cantilever wings. Where this is possible it is clearly a simple matter to arrange (without increasing head resistance) the weight distribution in any manner desired. It is to this point attention must, so far as fuel installation is concerned, be specially directed.

Section (*d*). Note on Use of "Forced Induction."

A good deal of attention had been directed in Germany to the question of "forced induction," the importance of which in relation to giant aircraft appears to be fully realised. Valuable experimental data on this subject is to be found in the "Technische Bericht." The details of the forced induction plant need not here be described. The principle, which is that of applying (when at high altitudes) air under pressure to the carburettors of the aeroplane motors, is well known and needs no explanation.

It has been successfully put in practice in the case of a German "Type A" machine (four motors of 260 h.p. each) by the installation of an additional 120 h.p. motor, driving a turbine "blower" which supplies air under pressure to the four aeroplane motors (and also to its own motor), by means of a common piping system. This machine, which, without the "blower" forced induction installation, has a ceiling (under normal load) of about 7,000ft., has actually reached an altitude of over 20,000ft. when using the "blower." The turbine "blower" and engine are heavy, but the results are without doubt most remarkable. No information as to the "life" of the motors under these conditions of higher working load is available. The conditions as regards the "life" of the motors under these circumstances would be analogous to using the engines continually at full power on ground level. The majority of Entente aeroplane engines would not stand this treatment. Unfortunately no information is available as to the effect on *range* caused by the use of the "blower." It is possible, however, in spite of the extra petrol consumption of the aeroplane motors (also of the "blower" engine) that due to the increased speed obtainable at high altitudes a considerably greater range might be attainable.

The whole matter is of very great importance to the future of giant aircraft, but the information at present available does not permit us to go beyond this statement.

There is yet another alternative by which this power of the motors can be maintained at high altitudes. The system involves designing the motor with a super (high) compression ratio, such that the throttle must not be fully opened until the machine reaches a certain altitude. This arrangement involves fitting some mechanics by which the throttle opening, or the fuel supply, can be automatically restrained until a certain minimum altitude is reached. This very necessary safeguard is most easily arranged for by means of a fuel pump which takes the place of the gravity tank. This arrangement is far preferable to the "blower" system as involving less mechanical gear.

IV.

CONCLUSIONS AND DEDUCTIONS FROM PAST EXPERIENCE.

In Part II. of this review we divided the examples of German giant aeroplanes into three separate classes, which we have referred to as "Type A," "Type B" and "Type C." Within these three separate types we were able to distinguish the various characteristic features of each group of machines, and from these characteristics to assess the future value of each "type" of design.

In Part III. we have examined the practical aspect of the various minor features of all the machines under review. This examination has revealed the

far-reaching effects of the fundamental circumstances which we had previously outlined in the introduction, and has at the same time accounted for the various departures from the normal standard practice in Entente countries.

We are now enabled, therefore, to obtain a clear and more comprehensive view of the whole subject, and to form some opinions as to the possibilities of future developments. More particularly are we able to adjust our preliminary conclusions as to the value of the Types "A," "B," "C," in accordance with the lessons of practical war experience.

Before proceeding any further with our main conclusions it is desirable perhaps to re-state the real objective aimed at in the development of giant aeroplanes. This is simply and entirely that of increasing the *useful load*.

An increased useful load can be reflected in a variety of ways, such as bomb carrying capacity, greater radius of action, etc. In any case the augmentation of the useful load is in itself a fundamental military advantage for all offensive purposes. Giant machines are therefore essential to every State or Government whose prestige and position depend upon military guarantees.

The unique advantage of the giant machine lies in the fact that its large useful load permits it to operate over great distances and to carry a very heavy load of bombs, with a minimum of effort in so far as personnel and "maintenance" are concerned.

To consider the "giant" machine from any other than a military point of view would be for our purpose unprofitable, and our conclusions, therefore, will have no intended connection with the "commercial giant" of the future, nor are they concerned with "commercial economy."

The military giant machine must have not only a large useful load, but the *maximum possible* useful load. What we wish to discover then is the simplest and most satisfactory way of producing and maintaining such a machine.

Our examination of actual German "giant" machines has not revealed any one type or concrete example which is in its present state worthy of imitation, or suitable as the basis of departure for the development of the future "giant" machine. At the same time we can now clearly distinguish that "line of least resistance" which shall lead to the establishment of a future type, the conception of which shall be based on considerations both fundamentally sound and capable of practical fulfilment.

The Selection of "Types for Development."

"*Type A*" *Giants*.—German experience clearly shows that real efficiency cannot be obtained from designs of this nature. Actual practice supports in fact the preliminary conclusions which we drew up in Part II. for these machines. At present, however, and until the development of a more suitable type takes place, these machines possess military features of some value.

"*Type B*" *Giants*.—The military disadvantages, mainly due to complication, and the constructural difficulties which our examination of these machines has revealed, renders this "type" quite unfit for further development. It is doubtful if, in the light of actual experience, these machines will even have the temporary "commercial" vogue which we had previously anticipated.

In any case the existing examples cannot be considered as a satisfactory basis for development; are totally unfit for military purposes, and can only serve as a warning in the future.

"*Type C*" *Giants*.—Unfortunately we have not encountered any concrete examples of "Type C" *giants*. Sufficient information has, however, been available to show us that, for the present, the "cantilever wing" type of design has immeasurable possibilities.

Enough has been said in the previous pages of this review to emphasise the marvellous adaptability of this "type" of design to the various and detail requirements of "giant" machines.

The all-metal construction, which is perhaps the main and principal feature of the "Junker" conception, is of great military value in any class of machine. With a "giant" machine, for which the provision of hangars is in any case a great difficulty, it assumes an even greater importance.

For the present the best, and indeed the only satisfactory, basis for the development of "giant" machines is contained in the genesis of the "Junkers" cantilever wing design.

Though this type of machine has not yet appeared in "giant" form, we are however in possession of sufficient information in regard to the normal procedure of development (as exemplified in other designs), such as to render the process of development comparatively simple.

The realisation, execution, or construction of machines within the range of this primary and basic point of departure, must necessarily vary in matter in matters of minor detail. It remains to extract from previous experience with other types of design, the guiding principles in all such matters.

NOTE.—Professor Junkers, whose connection with aviation is derived solely from his conception of his design, has since been appointed as Technical Director of the German Civil "Air Ministry," an appointment which may be taken as a guarantee of the fact that the German Government have grasped the immense importance of this latest development. Already a number of German firms are imitating in the design of "civil" machines the conception and construction of Professor Junkers' machine. Professor Junkers himself has revealed the fact that his present machine is a forerunner only of the future.

Every satisfactory military aeroplane is a monument to successful compromise. In spite of a multitude of detail and technical improvements, German ingenuity failed to take sufficient account of this fundamental and elementary principle, the neglect of which is emphasised by the failure of their largest "giant" productions. For the future then, it is essential that the initial conception of our giant machines —the definite *functions* of which must first have been decided upon—must be evolved upon a basis of compromise. Every detail must be studied in advance, the military requirements being embodied in the design rather than, as is so often the case, being considered as accessory features following the evolution of the machine. The successful designer must avoid the hypnotic influence of precedent, the reactionary tendency to build in miniature, and the fatal influence of complication. He must distil the knowledge gained from the failure of previous types, and profit from the successes of every detail in design. Above all he must bring to bear on the question of design every item of experience and experiment which shall tend to facilitate the practical working and "maintenance" of the completed machine when operating in the field.

Construction. The Dimensions of Giant Machines.

The military giant machine is essentially, as we have already seen, that aeroplane which concentrates within itself the maximum "offensive power." From this criterion there can be no departure.

Unless therefore the whole principles of flight are radically altered our giant aeroplane will be the *largest existing machine of its period.* On purely theoretical grounds this fact can be disputed; in actual practice as supported by evidence from every quarter it admits of no contradiction.

In order to fulfil their military duties it is essential that "giant" machines should be able to operate under all conditions and be at the same time independent of aeroplane hangars, the provision of which is always inconvenient and often

impossible. For this reason metal must predominate in the materials employed for construction.

The increase in overall dimensions of giant aeroplanes, for reasons which we have previously discussed, is not likely except in the far distant future to be a bar to progress.

The two principal reasons underlying the failure of previous and existing "giant" machines have been, in the case of one "type," due to excessive head resistance resulting from the lateral distribution of motors *exposed* to the wind; in the case of the other "type," due to *structural* limitations arising out of the excessive concentration of weights in the centre of the machine. We are now, however, in a position to avoid both these faults by regulating the weight distribution through the medium of fuel stored inside the wings, and to retain at the same time the combined advantages of both "types."

By the adoption of a bold policy in aeroplane design, by discarding existing standards in relation to factors of safety, and by abandoning any attempt at enlargement on previously accepted lines, we can obtain in "giant" aeroplanes an "over-all efficiency" equal to, if not exceeding, that possessed by the smaller machines of the present day.

In advocating, on account of fundamental considerations, the adoption of the "cantilever wing," we are not necessarily advocating the employment of a monoplane design. The arrangement and disposition of the supporting surfaces depends too much upon individual circumstances to allow of a limiting definition. "Cantilever wings" have been successfully employed in monoplane and also in biplane designs. The system is, in fact, applicable to either mono or multiplane structures, as the requirements of design may dictate.

The Power Plant.

The success of every aeroplane is intimately connected with the choice, installation and arrangement of the power plant. Giant machines form no exception to this rule, and indeed have in the past only served to emphasise its vast importance. The whole question of the power plant and its installation contains, in other words, the key to the achievement of the practical success and the military efficiency of every aeroplane.

Future "giant" machines demand the employment of aviation engines developing the maximum horse-power it is possible to obtain from a single motor. Since real "reliability" can be obtained only from the certain and continuous working of the individual aeroplane motor, so the number of motors to be employed should never exceed the maximum *minimum* which we have previously determined upon as the necessary military compromise in the form of a concession to possible mechanical derangements. Only when the required total horse-power cannot be obtained within the specified limited number of motors can this minimum be justifiably exceeded.

The real significance of these vital facts may be summed up in saying that the employment of a small number of high powered engines guarantees a success which cannot be approached by the use of a large number of low powered engines.

In aircraft, as in all other military matters, "complication" is the grave of efficiency. The ideal engine installation for giant machines must be generally, and throughout all its details, conspicuously simple. Accessory and additional mechanical contrivances, such as "shaft drives"—the presence of which is alien to practical efficiency and simplicity—must find no place in the military "giant" machine.

Such gearing as cannot be avoided, namely, that required for reducing the revolutions of the propeller shaft, must be chosen with regard to the special

circumstances of each individual case. This "reduction gearing" should be, for the sake of simplicity, incorporated in the engine unit itself.

The engine for military giant machines must of necessity be economical in fuel consumption.

In addition, the motors should be designed to give full power at high altitudes by the adoption of the "super" compression type of engine in conjunction with a "fool-proof" fuel control mechanism.

Propeller Arrangement.

While the question of propeller arrangement has been in the past one of some considerable difficulty, principally on account of the large number of motors employed, the future machine with a small number of motors will not be under the same disadvantage and special consideration need, therefore, no longer be given to this difficult problem. It is perhaps as well to mention that the adoption of the "super compression" system in an aeroplane motor allows the engine designer to adjust the number of revolutions corresponding to "full power" at the various altitudes in such a way that, at any rate for some time to come, the introduction of "variable pitch" propellers will be unnecessary and another complication be thereby avoided.

Present Possibilities.

Without in any way drawing upon resources of imagination it is possible to say definitely that immense improvements in the design, construction, "performance," general utility and efficiency of the "giant" machines are within the reach of immediate achievement. With the information already available in Entente countries, and the additional experience gained at the expense of Germany, the development of new "giant" aeroplanes can proceed without undue expense on lines which, backed by actual experiment and previous experience, cannot but ensure a full measure of success. Moreover, it is not necessary that the dawn of a new era in giant aircraft should await the birth of some unknown or novel principle; the past has furnished all the information necessary for the eclipse of present achievements.

THE

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Notices of the Royal Aëronautical Society.

Election of Members.

The following members were elected at a meeting of the Council held on Tuesday, March 15th, in the various grades as shown:—

Associate Fellow.—Capt. L. C. Bygrave, A.M.I.E.E.
Students.—P. W. Dorn, H. Fraser, G. R. Irvine, T. C. Sharwood.
Member.—Major J. Gumbleton Currie.
Associate Member.—Capt. T. Oyama, I.J.N.
Foreign Member.—W. F. Eade.

Wilbur Wright Lecture.

The annual lecture in memory of the late Wilbur Wright will be delivered by Major G. I. Taylor, at the Royal Society of Arts, John Street, Adelphi, on Tuesday evening, April 12th, at 8.0 p.m. The subject will be "Scientific Methods in Aeronautics."

Safety and Economy Committee.

The Council have appointed a committee comprising Colonel O'Gorman (Chairman), Colonel Bristow, Colonel L. F. R. Fell, Captain G. de Havilland, Wing Commander J. H. A. Landon, Captain G. T. R. Hill, Major G. H. Norman, Mr. H. Ricardo, Colonel F. Searle and Mr. R. McKinnon Wood, with the following terms of reference:—To discuss the question of the type of engine and mechanical arrangements, etc., required for the safe and economical working of an aeroplane carrying mails and passengers (*a*) between London and Paris, and (*b*) over a 500-mile route. Two meetings have already been held.

Bronze Medal.

At the last Council meeting it was decided to revive the award of the Society's Bronze Medal, which has been in abeyance since the outbreak of war, and to devote it to the encouragement of the preparation of original papers by Students. Details will be announced later.

Air Ministry Conference.

Captain G. de Havilland, O.B.E., and the Secretary attended on behalf of the Society a Conference on Subsidies for Cross-Channel Aerial Transport Com-

panies, held at the Air Ministry, on Thursday, March 10th, with Lord Londonderry in the chair. Following on the conference a memorandum was forwarded calling attention to the necessity for bearing in mind the needs of designers and the construction side of the industry in order to ensure development in design.

Donations.

The Council desire gratefully to acknowledge the gift of lantern slides for the Society's loan collection from the Westland Aircraft Works, and of a copy of "Telegraphy, Aeronautics and War," by Sir Charles Bright, F.R.S.E., from the author.

Committees.

The usual monthly meetings of the Council and Committees will take place as follows:—Tuesday afternoon, April 19th, Lectures and Publications Committee, 4.0 p.m.; Candidates' Qualifications Committee, 4.30 p.m.; Council, 5.0 p.m.

Council.

As a result of the elections at the Annual General Meeting, on March 31st, the Council is now constituted as follows:—Chairman—Air Commodore H. R. M. Brooke-Popham, Vice-Chairman—Brigadier-General R. K. Bagnall-Wild, Dr. L. Bairstow, Major F. H. Bramwell, Wing Commander T. R. Cave-Browne-Cave, Sir Robert Hadfield, Captain G. de Havilland, Prof. B. Melvill Jones, Major A. R. Low, Lieut.-Colonel J. T. C. Moore-Brabazon, Lieut.-Colonel A. Ogilvie, Lieut.-Colonel M. O'Gorman, Dr. A. J. Sutton Pippard, A. V. Roe, Major-General Sir R. M. Ruck, Colonel the Master of Sempill, Major R. V. Southwell, Lieut.-Colonel H. T. Tizard, Brigadier-General J. G. Weir, Major H. E. Wimperis.

W. Lockwood Marsh, *Secretary.*

ANNUAL GENERAL MEETING.

The Fifty-Sixth Annual General Meeting of the Society was held in the Society's offices, 7, Albemarle Street, London, at 5.0 p.m., on Thursday, March 31st, 1921. The Chairman, Air Commodore H. R. M. Brooke-Popham, C.B., C.M.G., D.S.O., A.F.C., presided, and the following were present :—

Council.—Brigadier-General R. K. Bagnall-Wild, Wing Commander Cave-Browne-Cave, Sir Mackenzie Chalmers, Major A. R. Low, Dr. A. J. Sutton Pippard, Colonel the Master of Sempili, Major H. E. Wimperis.

Members.—F. W. Bourne, R. M. Balston, C. F. Dendy Marshall, F. P. Walsh, G. E. Page, F. K. McClean, Sir Charles Bright, J. L. Pritchard, W. O. Manning, H. Glaser, A. P. Thurston.

Dr. Sutton Pippard, Mr. J. L. Pritchard and Mr. W. O. Manning were appointed scrutineers of the ballot for the election of Council.

The Chairman in presenting the Council's report and balance sheet said :—

There has been considerable financial improvement during the year, though there is still a deficit on the year's working of £481 3s. 4d. When compared with the similar figure of over £1,780 last year, the Council feel that a substantial advance has been made. The fact remains, however, that the balance sheet still shows a debit of £1,542 19s. 11d., which it will take some years to wipe off in the ordinary course of events. This subject is dealt with in detail in the Council's Annual Report printed in the March issue of the JOURNAL.

In spite of the exercise of economy, activities have if anything slightly increased. A good programme of lectures was delivered during the session just closed, and lectures have also been given in various provincial towns, notably a course on "Aircraft Steels and Materials" to the students of Sheffield University. I myself recently gave a lecture in Manchester which was well attended, and there is every reason to hope may lead to increased interest in that district. Efforts have been made to improve the interest of the JOURNAL, and more original articles have been printed than has been the case for some years, notably Mr. Scoble's important paper on "Cables," and the recently published articles on "The Development of German Giant Aircraft." It is hoped to arrange for further "outings" on the lines of that to the National Physical Laboratory in January. The "Safety and Economy Committee" which has been appointed is doing good work in thrashing out some of the improvements which are desirable to improve the reliability and economy of commercial machines. It is serving the useful purpose of bringing together round one table people representing various interests that do not otherwise meet, and is doing work which is not covered by such bodies as the Aeronautical Research Committee.

I wish to point out that the chief way in which members can help is by trying to get new members to join. There must be a large number of potential members who have never joined simply because they have never been approached. Every member can help by thinking over who is likely among his circle of friends. More members means an improved financial position, which will react by enabling the Society to launch out in wider fields of activity.

Technical members can also help by offering to write articles for the JOURNAL giving the results of any minor researches, etc., which they have been carrying out.

It is difficult to keep the Library up-to-date as there is no money for purchasing books, and we have to rely entirely upon publishers to send review copies, and on the kindness of those reviewing the books to return them after dealing with them. This should not be the case, and it should be possible to rely upon, at any rate, any member of the Society who writes a book presenting a copy to the Library.

It also helps the Society if technical members quote the abbreviated titles (F.R.Ae.S. and A.F.R.Ae.S.) with other distinctions when writing articles in the Press.

It is proposed to endeavour to increase the interest of students by offering the Society's bronze medal annually for the best student's paper submitted, and by arranging for students' meetings for purposes of debating among themselves. In the latter connection it is hoped shortly to be able to announce the donation of a prize annually for the best paper initiating discussion at one of these students' meetings.

The resolution was seconded by Brigadier-General Bagnall-Wild and passed unanimously.

The Council's amendments to the Rules were then proposed by Brigadier-General Bagnall-Wild, seconded by Colonel the Master of Sempill, and (subject to an amendment proposed by Mr. Dendy Marshall to Rule 25A that in place of the words " on any notepaper heading or business announcement " should be inserted " in any announcement of the nature of an advertisement ") were passed unanimously.

The rules and regulations for election to Fellowship and Associate Fellowship were proposed by Wing Commander Cave-Browne-Cave, seconded by Major H. E. Wimperis, subject to the deletion of the word " fund " after " suitable donations to the Library " on the first page. The resolution was passed *nem. con.*

The Chairman then said that he would like to express the Council's thanks to the Secretary, Colonel Lockwood Marsh. He had written the paragraph in the report himself, not by way of putting in something nice but because he really felt it, and he did think that a tremendous lot was due to the Secretary for putting the finances of the Society on a proper basis and for the way in which the Society had been run generally. He felt that the Society was to be congratulated on having got Colonel Marsh and on keeping him.

The scrutineers then presented the result of the ballot, and the following members were declared elected to serve on the Council for the two years ending March, 1923 :—

Dr. L. Bairstow, C.B.E., F.R.S., Wing Commander T. R. Cave-Browne-Cave, C.B.E., Sir Robert Hadfield, Bt., F.R.S., Captain G. de Havilland, O.B.E., A.F.C., Lieutenant-Colonel J. T. C. Moore-Brabazon, Lieutenant-Colonel A. Ogilvie, C.B.E., Lieutenant-Colonel M. O'Gorman, C.B., Colonel the Master of Sempill, A.F.C., Major R. V. Southwell, Lieutenant-Colonel H. T. Tizard, A.F.C.

The meeting concluded with a vote of thanks to the Chairman, proposed by General Bagnall-Wild, seconded by the Master of Sempill, and carried unanimously.

AIRCRAFT v. SUBMARINES.

LECTURE DELIVERED IN GLASGOW ON 15TH DECEMBER, 1920, BY

COL. L. H. STRAIN, O.B.E., D.S.C., BEFORE THE SCOTTISH BRANCH OF THE SOCIETY.

The Air Ministry, in granting me permission to deliver this lecture, have asked me to make it clear that "the statements made are based entirely on my own knowledge and the opinions expressed in no way reflect the official views." I should like to acknowledge the courtesy of the Air Ministry in giving me permission, and to say that I should be surprised if some of my opinions were in accord with the official view.

Towards the end of the war, although submarines were still doing a considerable amount of damage to shipping, the Navy was rapidly getting their measure.

Submarines were being sunk faster than the enemy could build; their submarine service had been made so hazardous that it was increasingly difficult for the enemy to man their submarines and maintain the morals of the crews during attempted operations.

This result was not achieved by any one arm of the Navy, nor by any particular invention, but was effected by the intensive use and close co-ordination of practically all the resources which the Navy could command.

British submarines stalked enemy submarines, a dangerous pastime where the hunter never knew from moment to moment that he had not become the hunted.

Mystery ships—"Q boats" they were called—cruised about inviting attack and even allowed submarines to torpedo and then shell them before showing their teeth, in order to make certain of sinking the attacking submarine.

Hunting flotillas, specially equipped, covered the danger zones listening on hydrophones for the distinctive sound of a submerged submarine's engines, and having located one, kept on the trail like a pack of beagles until they had a chance to drop depth charges effectively or until the submarine's batteries were exhausted and she had to come to the surface to fight or make a bolt for safety. Destroyers, sloops, trawlers, drifters, yachts, motor launches, even old cruisers, all played their part while there was scarcely a branch of science which the Navy did not invoke to assist in the defeat of the submarine.

Included in the organisation, and as an essential part of it, aircraft of all descriptions were used and became of steadily increasing importance as they developed in efficiency and as their proper use was better understood. It is with the part they played and the results they obtained that this paper is concerned.

At the beginning of the war senior naval officers in charge of anti-submarine operations were inclined to over-rate the value of aircraft. They realised that a seaplane travelling at 60 knots, in weather conditions which gave fair visibility, could search about 600 square miles of water in an hour, while a trawler steaming at 10 knots, having a much smaller horizon visible from her bridge, could not patrol more than 40 square miles in the same time. They had heard that from high up one could see through the water and they thought that it was only necessary to get a seaplane over a submarine for the latter to be discovered, her position indicated to the seaborne patrols, and the submarine to be sunk.

It is quite true that a seaplane can patrol 15 times as much water as a trawler, provided she stays in the air. It is also true that an aerial observer can see under the surface of the water provided the conditions are favourable. In the Mediterranean photographs have been taken of submerged submarines, but when

there is low cloud under water visibility is very small and where the sea is shallow and disturbed the water becomes muddy and therefore opaque.

The North Sea is almost an ideal field of operations for submarines; it is so shallow that in most parts a submarine can lie on the bottom without having to waste fuel and without making any noise to indicate her position. The shallow water is constantly churned up by high winds so that it is thick and cannot be seen through from the air; the visibility on the surface is usually poor and low cloud is common, so the maximum use cannot be made of aircraft.

At the beginning of the war there were no trained aerial observers. There were only about 20 seaplanes around the British coasts which were in any degree fit for active service, and these had extremely unreliable engines. As an example, the seaplanes at Dundee and Granton had 160 h.p. Gnome engines which broke down completely on an average every 2 hours 44 minutes, yet the machines had to be sent on two to three patrols.

Small wonder that aircraft proved a bitter disappointment to senior naval officers. Not only did they have no tangible success, but they were constantly breaking down at sea, pilots and observers were lost, and destroyers had to be diverted from their regular duty or taken from their hard earned rest to search for missing machines and ran the risk of being torpedoed while picking up a seaplane or while towing her home at slow speed.

The inevitable result was that many senior naval officers proclaimed aircraft as being more bother than they were worth and ceased to ask for their assistance. Consequently the development of sea-going aircraft was retarded and the efforts of the R.N.A.S. were largely devoted to performing "stunts" on the Western Front in competition with the R.F.C., or in raids on the German coast from seaplane carriers; gallant work, but without much material effect on the course of the war.

For a time development in seaplane construction stood still, but slow progress was made in other branches of aviation. Early in 1915 the kite balloon was successfully adapted for work at sea while being towed by a ship. Shortly afterwards the submarine searching airship or "blimp," composed of an old-fashioned aeroplane fuselage carrying a pilot and observer suspended from a small envelope filled with hydrogen, made its appearance.

These, with such seaplanes as were not required for the seaplane carrying ships or were unsuitable for them, were scattered round the coast and did a lot of haphazard work with, however, little effect. Although experience was gained and gradual improvement was attained, it was not until the War Staff at the Admiralty was reorganised by Lord Jellicoe that there was any marked development in the use of aircraft for submarine hunting.

One department of the War Staff was devoted exclusively to anti-submarine measures and was put under the charge of Admiral Duff, with very wide discretionary powers. Parts of the organisation were an anti-submarine division anxious to explore and co-ordinate every conceivable means of defeating the submarine, and a section of the Air Division of the War Staff devoted solely to anti-submarine warfare and working in close co-operation with the anti-submarine division.

An organisation embracing all areas of submarine activity, a plan of operations and a programme of development were settled. The provision of personnel and their special training, the selection of suitable types of aircraft and their supply in sufficient quantities, the equipment and armament of aircraft for anti-submarine work, the distribution of intelligence, arrangements for signalling and co-operation with surface-borne craft were all decided on.

Practically a new service came into being which had no inconsiderable effect in countering the activities of enemy submarines.

Owing to the immense importance attached by the War Cabinet to the bombing of Berlin and their direct orders that the provision of anti-submarine aircraft should be subordinated to the equipment of a large independent air force for that purpose, the anti-submarine organisation and programme of development had not nearly attained their full growth by the time the Armistice was concluded.

Much, however, had been done and its effect was abundantly clear on the course of the enemy's submarine campaign.

There are three principal ways in which aircraft can be used effectively against submarines.

1. They can attack the submarine bases, sinking submarines in port, destroying their torpedo and other stores, wrecking the machinery and appliances for repairing and refitting the submarines, and killing personnel.

   Unlike work at sea, where one may patrol for months without sighting a submarine to attack, there is always a valuable objective in the base itself and persistent attacks are bound to have a considerable effect.

2. Aircraft can patrol very large areas at sea, attacking submarines when found, directing sea-borne patrols to the place and compelling submarines to remain submerged, when their effective range is greatly reduced.

3. Aircraft can be used defensively to escort and protect shipping and locate minefields.

Let us deal with these three matters in turn and examine what success was attained and some of the reasons for failures.

1. Attacks on Submarine Bases.

It is generally known that for operations in the southern part of the North Sea the Germans had submarine bases at Ostend, Zeebrugge and Bruges. A large naval air station was maintained at Dunkirk principally for the purpose of attacking these bases.

In order to give some idea of the intensity and persistence of these attacks I have collected the figures of bombs dropped in these submarine bases between April and September, 1918.

In all 10,432 bombs were dropped, weighing 847,904lbs. or just on 334 tons of bombs. On the average 57 bombs were dropped on them every day or night.

The figures are :—

	Bombs.	lbs.
Zeebrugge	2,254	189,871
Ostend	2,841	184,000
Bruges	4,284	378,032
Canal objectives	833	47,339
Submarines in harbour or entering or leaving	220	48,662
	10,432	847,904

The bombs varied in weight from an enormous thing weighing 1,600lbs. down to little 16lb. and 40lb. incendiary bombs. Think what this meant to the people and objectives below!

Think also of the arduous work required from those in the air and remember that the anti-aircraft fire was probably more intense than anywhere else on the Western Front and that hosts of enemy fighting machines were always guarding these objectives.

Bombing by way of counter-attack was also common. For instance, on one night Dunkirk Naval Air Station had 300 bombs dropped on it. Not a soporific for tired personnel.

Many a good man was lost to the Naval Air Service there, but his work was not thrown away; it exercised a material effect on the enemy submarine campaign.

In order to protect their submarines from bombs the Germans built immense concrete shelters, which in itself shows the straits they were in to maintain their submarine campaign in the southern part of the North Sea. Even these shelters were insufficient to protect the submarines, which could be caught entering or leaving, and even when they were under cover a direct hit from a large bomb caused more than one such shelter to collapse.

After the blocking of Zeebrugge and Ostend by "Vindictive" and the other ships on St. George's Day and the enemy's experience of some months of intensive bombing from the air, bombardment from the sea and mining off these bases, they were abandoned. The enemy's North Sea submarine campaign was carried on afterwards from the German bases in the Heligoland Bight, which were much further from their objectives.

These other enemy submarine bases in the Heligoland Bight and those in the Adriatic and at Constantinople were too far away for them to be attacked with that regular persistence which is necessary to secure moral effect or real material damage. Occasional raids were made which had no substantial effect except in containing a large number of anti-aircraft guns which would have been more troublesome elsewhere.

2. Attack on Submarines at Sea.

The old cookery book's recipe for hare soup, which began "first catch your hare," applies equally to submarine hunting. The submarine must be found before it can be destroyed, neither of which is easy.

To have the best chance there must be specially trained officers in suitable aircraft working in close co-operation with surface and being supplied with the latest intelligence regarding the movements of enemy submarines.

Training.

The aircraft may be the most perfect in the world, but it is in vain to expect results unless the observers in the machines are trained to distinguish enemy submarines from our own, what a periscope looks like, and from what height it can be seen, the tactics employed by enemy submarine commanders, how they attack and how they avoid attack; the performance of various types of submarine, what speed they are capable of on the surface and submerged, their endurance while under way submerged, how long it takes them to dive, what depth they can dive to, how long they can lie on the bottom and what sort of roosting ground they will choose. Having got in touch with a submarine the observer requires to be able to drop bombs accurately (he seldom gets a second chance), to know how far ahead to aim if the submarine is at periscope depth, how much further ahead if the submarine is running deep, when machine-gun fire may be of use, how to plot the position of the submarine accurately and how to communicate the information to surface hunting craft, to convoys and to his base, all of which requires careful and lengthy training; much more training than to become an efficient pilot. In the early days of the war observers were quite untrained and only picked up useful knowledge from their own keenness to learn and their association with naval officers of submarines, signal, navigation and other branches.

Latterly a special submarine hunting school was started where, in addition to learning all the subjects outlined above, observers had opportunities of prac-

tising with our own submarines and surface hunting craft, going to sea with them, and, what was equally important, officers of the submarine and submarine hunting services were taken up in aircraft so that they could appreciate the advantages and the difficulties of the Air Service.

It is noteworthy that some four months after the British school was started Germany woke up to the necessity of such a school and started a similar one.

Suitable Aircraft.

The first essential of aircraft for anti-submarine duties is that they should have a perfect view ahead and underneath the machine in order that the observer should have the best chance of sighting and bombing a submarine before she sees the aircraft and dives. Aircraft of the "pusher" or "twin tractor" type have this quality and obtained much better results than the usual tractor type, where the observer's view ahead is obstructed by the engine and his eye is tired by the propeller flicker.

The machine should be as noiseless as possible. The noise of aero engines is very insistent and aircraft are as a rule discovered by sound long before they are seen, particularly in conditions of low visibility or if they are coming from the sunny side. Silence, which is almost as important for land bombing machines, was ignored until late in the war, but at the request of the anti-submarine service experiments were undertaken and some success was obtained, but the complete silencing of the engine without material loss of power and the silencing of the propeller has not yet been solved. When it is the value of aircraft, not only for anti-submarine work but for practically all war service, will be more than doubled.

Great speed is not necessary for anti-submarine work, but long endurance is essential.

Machines should be capable of alighting on and rising from a fairly rough sea. This is necessary for several reasons:—

1. Hydrophones are instruments like telephone receivers, which are very sensitive to underwater noises. Some types can pick up the sound of propellers even 15 miles away. Seaplanes can be fitted with hydrophones so that they can alight, listen for the distinctive sound of a submerged submarine and indicate its position. In this they have a great advantage over surface craft as submarines have hydrophones on which they can hear the propellers of surface craft and in shallow water like the North Sea can lie quietly on the bottom until the absence of sound assures them that it is safe to come to the surface.

The sound of an aero propeller, however, even from a seaplane which has alighted close to the submarine, cannot be heard on her hydrophones, so seaplanes able to alight and use hydrophones can hunt a submarine when she does not know she is being hunted, which surface craft cannot do.

A certain measure of success was obtained in the Ægean with hydrophones used from seaplanes. Later in the war flying boats used round the British coast were being fitted with them, but as these boats had difficulty in rising from anything but calm water with a war load the occasions on which they could be used were few.

Consider the advantage of hydrophones fitted to seaplanes which can alight on and get off a fairly rough sea. A submarine is located in a particular area by night or day. A flight of four such seaplanes is sent out. Three spread themselves out at extreme hydrophone range, say five miles apart, and alight to work hydrophones, the fourth remaining in the air to attack as directed and to work wireless. Nothing is heard, so the three rise, fly five miles further on and again sit down to listen. In an hour they can make a hydrophone search of an area of 400 square miles without the submarine knowing she is hunted unless she comes

up and uses her periscope, when the machine in the air has the chance of sighting and bombing her.

If the machines on the water hear a submarine the three should each be able to get a bearing of the sound and plot the position of the submarine with sufficient accuracy to taxy over the spot and depth-charge it.

2. The capacity of alighting at sea is also valuable for the sense of security it gives to the personnel. Flying aeroplanes out of sight of land at sea, day and night out, is very trying even to the best personnel. Engine failure means probably drowning, certainly an unpleasant cold bath, which after some days of routine patrols creep into the back of their minds and they cannot concentrate their entire attention on examining the sea as they can if they feel secure. It is noticeable that submarines were sighted much oftener per 1,000 miles flown by seaplanes than by aeroplanes.

3. If caught by fog a seaplane can come down and wait until it clears while an aeroplane has to make a hazardous return to land.

Submarine hunting aircraft should also be able to carry a heavy load of bombs.

Where work has to be done within flying distance of the enemy coast these machines or escorting machines must have good fighting qualities.

We lost many valuable machines and men through the German seaplanes being far superior to ours in these respects. The German seaplanes were so seaworthy that they could alight outside the North Hinder lightship, exposed to the whole force of the North Sea, and await our patrols, then rise and with their greater speed and power of manœuvre fly round our machines, attacking as they chose and breaking off the engagement at will.

One instance of such a fight deserves to be told. On 18th July, 1918, two Short seaplanes with two Camel aeroplanes as escort left Westgate on anti-submarine patrol. They were attacked by seven enemy seaplanes, six of which were small fighters capable of outflying the Camel aeroplanes. One of the enemy seaplanes was shot down. The large enemy seaplane engaged in a duel with one of the Shorts. Each winged the other and both came down on the water. They "taxied" towards one another, firing as they went. The last seen of either machine was both machines on fire close to one another still firing their machine-guns. R.I.P. The other Short seaplane was also lost.

These desiderata indicate that the seaplane, or better still the amphibion which can alight on or rise from either water or land, is the most suitable for anti-submarine work.

We never even approached this ideal. Until the end of the war the great bulk of the work was done by the old-fashioned Short seaplane which had a poor view ahead and below, was noisy, could not carry a great weight in bombs and was not very reliable.

These were assisted by the little airships—"blimps"—which were very conspicuous and so slow that in the Mediterranean the more dashing of the submarine commanders used to come to the surface up wind of the "blimp," steam into the wind so that the overtaking speed of the airship was small, and have target practice with their gun at the airship, to the discomfiture of the latter.

The enemy submarine commanders got to know and appreciate the tactical qualities of these aircraft and for the time evaded them.

Then the so-called "Large America" flying boat, designed by Wing-Commander Porte of the British Naval Air Service, made its appearance. This type had twin engines which gave the observer a perfect view ahead, could carry

heavier bombs than Short seaplanes and, having a greater endurance, could venture further to sea.

A notable example of the seaworthiness of these seaplanes was the case of a Large America which came down in very bad weather near Heligoland. The weather was too bad for the Harwich light forces to search for them and the machine was given up as lost. Her crew, however, being seamen, had rigged a sea anchor to which they rode for three days, drifting across the North Sea, when the storms having abated, they got their engines going and "taxied" into harbour under their own power.

As is usually the case in modern warfare when a new invention is sprung on the enemy, the flying boat enjoyed a considerable success. The periscopes of enemy submarines could not at the time see more than 30° from the horizontal, they were thick and when travelling at 3 or 4 knots made a very noticeable "feather" in the water. Before the enemy realised their disadvantage the flying boats had sunk six enemy submarines and damaged others.

Success in attack, where some new invention is responsible, is always met by improvement in defence. The periscopes of enemy submarines were made thinner, as thin as a lusty walking stick, and did not give as pronounced a "feather." An "altiscope," which could examine the sky before a submarine came to the surface, was fitted in each boat, and submarine commanders with their new respect for the powers of aircraft became much more wary when within reach of air stations.

The areas where submarine activity became most pronounced by day were a long distance from air stations and their work in the immediate neighbourhood of air stations was carried on mostly by night.

To meet the first it was necessary to improvise mobile bases for aircraft. The first experiment was carried out in the Ægean, where the tide is small and where places suitable for advanced bases are common. Machines flew to these places, followed by a trawler fitted with a gun to protect them and carrying stores and air ratings. Machines—seaplanes—were filled up with fuel and operated from the advanced bases and were able to patrol areas where their presence was unsuspected, so worrying submarines into finding spheres of operations still further afield.

In British coastal waters the same practice was instituted, a ship, "Aviator," was adapted as mother ship and mobile base to seaplanes working off the coast of Ireland, moorings for aircraft were laid down in sheltered spots and in this way the range of aircraft was largely increased.

To counter submarines operating at night aircraft seemed of very little use; there were only two ways in which they could be of much assistance, firstly by fitting them with hydrophones so that they could listen for submarines, and secondly, fitting them with parachute flares which would descend slowly, lighting up a large radius of water and compel submarines within their radius to submerge, so preventing their getting into position to attack shipping or lay mines and, still more important, preventing them recharging their batteries and so limiting their sphere of activity.

Statistics compiled by the Intelligence Division showed that the average length of cruise of submarines operating on the east coast of Britain was reduced from seven to five days, a result which they attributed very largely to the intensive use of aircraft keeping submarines from the surface and so exhausting their battery power.

Armament.

To attack a submarine successfully not only requires special armament but also necessitates special training. Consider the problem :—

A submarine may be caught on the surface or it may have had warning and submerge before the aircraft is over her in a position for bombing.

If she is on the surface, bombs which are fused to detonate below the surface may not injure her even if they make direct hits. There were at least two cases where bombs with time fuses made direct hits on submarines on the surface, splintered without detonating and did little damage. A modern submarine is a strongly built affair with two skins, one of them thick, and to injure her on the surface either small armour-piercing bombs are required or small high velocity shell from a quick-firing gun, either of which will pierce both skins and prevent her submerging. With older type submarines, or the small German mine-layers, which have only one skin, machine-gun fire may be effective and an observer must be able to recognise types of submarines and deal with them accordingly.

One example is instructive. An old British submarine, C25, had been doing coastal patrol off Harwich and was coming off duty when a flight of aircraft was observed coming towards her. They were thought to be British aircraft and no special precautions were taken. Suddenly bombs began dropping all around C25 without doing material damage, then machine-gun fire was opened from the aircraft, which were German, and some of the bullets pierced the skin of the submarine. She had started to submerge but had to come up again as water was pouring in and causing a poisonous gas from the electric batteries. The seaplanes had expended their bombs and alighted around C25. The submarine's captain and one rating went up to the conning tower with their machine-gun. They were killed and the machine-gun lost overboard.

The sub-lieutenant tried to ram the seaplanes but his rudder was jammed, so both sides lay impotent, unable to damage the other.

At last the seaplanes rose and flew back to their base for more bombs.

An E class submarine, which had seen the end of the action, came up and took C25 in tow. The seaplanes returned and the E boat quietly submerged and lay on the bottom at the end of her tow line while the second abortive attack was delivered, then rose unsuspected by the seaplanes and finished towing C25 to harbour, the survivors of C25's crew having flatly refused to leave their ship although they knew the second attack was coming and that they could do nothing in reply.

If, however, the submarine has submerged before aircraft are in position to bomb her the problem is more complicated. She may have submerged only to periscope depth, about 26 feet, or she may go to her maximum diving depth, about 180 feet. A bomb fused for the one depth will not injure the submarine at the other, while one fused as a compromise between the two depths will injure a submarine at neither.

The observer has to make up his mind immediately. If there are deep minefields in the neighbourhood, known to the enemy, it is unlikely that he will risk going deep. A knowledge of the soundings in the vicinity will be another guide. Local knowledge and quickness of perception are his chief resources. If the machine can carry sufficient weight, bombs dropped to straddle both depths will give much more chance of damaging the submarine if dropped far enough ahead.

How far ahead to drop the bombs also requires expert knowledge and practice. The observer may only see a thin streak of oil or a tiny line of air bubbles. Air comes to the surface much faster than oil and both rise more slowly than one would suppose. The calculations which were made early in the war proved to be wrong and many a submarine must have got away uninjured through bombs being dropped too far astern to do damage. But even if the observer knows how far to aim ahead for particular depths at which the submarine may be he still has to make up his mind and make the necessary allowance for whether

the submarine is at the periscope depth or running deep; whether she is still on her dive, when the advancing speed will be small, or whether she has taken up her depth; whether she is likely to hold her course or turn to port or starboard.

The only satisfactory method is, like the use of a shot gun at a snipe, to strew the whole area with bombs fused to detonate at all depths, for which, if aircraft are to deal with the submarine unaided, patrols should be undertaken by a flight of weight-carrying aircraft, working together, rather than by single machines. As an illustration:—

On 24th July, 1917, five large flying boats were patrolling in the vicinity of the North Hinder lightship. One of them sighted a submarine just submerging and turned to attack it. The other four followed her and all dropped their bombs in a salvo around where the submarine had dived. That was the end of the German submarine U.C.1. One seaplane might have sunk her, but five seaplanes dropping ten 230lb. bombs together made a practical certainty of it.

More certain results can be obtained from close co-operation between aircraft and surface hunting craft, which can carry a much greater weight of explosives than is at present possible in aircraft. The subject of co-operation is itself a large one which I do not propose to deal with except to say that the three essentials are:—

A knowledge of the powers and deficiencies of the arm with which one is co-operating.

Adequate signalling between the two arms and perfect trust in the other arm knowing and carrying out its own job.

Organisation.

In other respects rapid improvement was made in the last two years of the war.

With experience the intelligence system had been developed and the deductions of the Naval Intelligence Division made more readily accessible to those in charge of operations.

From logs and other papers captured in enemy submarines a great deal had been learned about the personnel of their submarine service, their tactics, the equipment and performance of their various types of submarine.

The tracking department could tell with considerable accuracy not only how many submarines were operating around the British coasts, but also which individual submarines were at sea, who were their commanding officers, how long they had been at sea and when they would probably require to return to port.

Often, too, the tracking department could give the exact position of a submarine and forecast her probable course.

With this information at the disposal of those in charge of operations, submarine hunting was rapidly becoming less of the needle in the haystack variety, and the work of surface craft, British submarines and aircraft could be co-ordinated to harry enemy submarines increasingly.

Defence Work.

In addition to their work in bombing submarine bases and hunting submarines at sea, aircraft were largely used latterly for defence against attack by submarines.

This took the form of escorting convoys and single ships, patrolling swept channels and convoy routes to prevent submarines coming to the surface to examine their targets and get into position to attack; in locating minefields laid by the submarines and destroying mines which had come to the surface.

Escort Work.

The obvious success in escorting surface craft with aircraft caused aircraft to be devoted much more to this duty towards the end of the war, and in order that aeroplanes also should be used the coastal convoy routes were brought more inshore.

The figures for 1918 are:—4,869 escort flights were undertaken by seaplanes and aeroplanes. Only two vessels were attacked while under escort and on one of these occasions the aerial observer saw the track of the torpedo starting and was able to signal and warn the ship aimed at in time for her to alter course and avoid the torpedo. 2,141 escort flights were made by airships, only one vessel being attacked while being so escorted and on that occasion the airship was five miles away from the ship when she was attacked. 131 escorts were made with kite balloons towed from surface escorting craft during which three vessels were attacked. On two of these occasions the approach of the torpedo was observed from the kite balloon and the third attack was made at dawn when visibility was very bad.

In comparing these figures it must be remembered that the length of escort undertaken by airships was about three times that of seaplanes and aeroplanes, while kite balloon escorts average several days duration.

The success of aerial escort is not so much due to aircraft being able to prevent attack as to the fact that the track of a torpedo is very apparent from the air, and a submarine commander knows that as soon as he makes an attack the position where the torpedo track began will be bombed by the aircraft and the water-borne escorts will be directed to the place to depth charge it heavily. This changed submarine attacks on defenceless merchantmen from being a safe pastime for the Hun into a dangerous operation which he was not so anxious to undertake.

For this work airships were in many respects better than seaplanes or aeroplanes, they have a longer endurance and can cruise round a convoy at slower speed, but if an attack is delivered an airship takes longer to get over the torpedo track and bomb it, particularly if the attack has been delivered up wind of the airship.

There is only one instance of a submarine having been sunk by an airship; that was the Scotch built airship R.29, which was not intended for unit submarine work, but which found and bombed U.B.115 on 29th September, 1918, and then directed two torpedo boat destroyers and three trawlers over the spot. They finished off the submarine with depth charges.

There is also only one recorded case of a submarine having been seriously damaged by an airship.

This lack of success is not to be wondered at when one considers what obvious features of a seascape airships are, even when seen through a periscope, and how long it takes an airship to get over the position where a submarine has submerged. They were very useful scarecrows when acting as escorts, but it is doubtful whether their work would not have been as well done by kite balloons at infinitely less cost in personnel and material, freeing many men and much material for the heavier-than-air branches.

In the weather when airships usually patrol even a periscope is fairly conspicuous and submarines do not like to operate.

For example, take the aircraft operating on the north-east coast of England from 1st July to 30th September, 1918. There were 58 days on which no flying was done by airships. On these days 40 attacks were made by submarines on British shipping and 29 sightings, mostly followed by attack, were made by seaplanes and aeroplanes on enemy submarines. Airships in that area only sighted submarines on four occasions during the three months.

Results.

The defensive value of aircraft in preventing attack on shipping, locating minefields and diverting traffic from danger zones cannot be assessed in figures. No one can hazard a guess at the numbers of ships saved or the tonnage of supplies brought safely to Britain because of the work of aircraft. It must be very large.

Other results are known and give some indication of the value of aircraft in anti-submarine warfare.

In 1917 submarines were sighted from aircraft on 169 occasions, of which they were attacked on 106.

In the nine months of 1918 submarines were sighted 192 times, of which 130 resulted in attack.

It must be remembered that in 1918 aircraft were much more devoted to escort work which accounts for the greater mileage flown for every submarine sighted.

As an indication of the expansion of the work, the distance flown by aircraft on submarine patrol in home waters in 1917 was 1,526,475 miles, while in the nine months of 1918 this had increased to 4,801,347 miles, nearly three times as much.

Prior to 1917 only one submarine was known to have been seriously damaged by aircraft. That was in 1915.

In 1917 seven were sunk and 15 seriously damaged by aircraft. Six of the submarines sunk, viz. :—

U.C. 36 on 20th May,
U.C. 1 on 24th July,
U.B. 20 on 29th July,
U.B. 32 on 18th August,
U.C. 72 on 22nd September, and
U.C. 6 on 28th September

were sunk by large America seaplanes unaided.

One submarine, U69, was sighted from a kite balloon towed by "Patriot," which was directed where to drop her depth charges and sank the submarine.

In 1918 four submarines were sunk, six seriously and 20 slightly damaged by aircraft. All the submarines sunk were finished off in co-operation with surface craft. They were :—

U.C. 49 on 31st May,
U.C. 70 on 28th August,

both of which were found by fairly fast aeroplanes with a good view ahead.

U.B. 83 was sighted from "Ophelia's" kite balloon which directed her over the spot, and U.B. 115 was sighted from airship R.29 on 29th September and sunk by her in co-operation with destroyers and trawlers.

Everyone engaged in the anti-submarine campaign will always regret that the ultimate test of their organisation was not carried through. In October, 1918, the tracking department of the Intelligence Division traced a hiving homewards of enemy submarines and their concentration in the North Sea off the entrance to the Firth of Forth.

From this and other indications it was apparent that the concentration of submarines was to play an important part in Germany's last gamble, a general naval action.

The British anti-submarine organisation was put on a mobile basis and among other arms aircraft were concentrated to meet the enemy submarines.

Unfortunately the enemy fleet refused to put to sea and the last test of whether we could rely on ourselves to defeat the submarines or whether, as politicians want, we should ask a League of Nations to prohibit their use in future wars and so confess our impotence remains undecided, but I believe firmly that so long as the Navy and the new Air Force work whole-heartedly together and are given enough money for practice flights and experiment, we need not fear the submarine in future campaigns.

PROCEEDINGS.

SEVENTH MEETING, 56th SESSION.

The Seventh Meeting of the Fifty-Sixth Session of the Royal Aëronautical Society took place in the hall of the Royal Society of Arts, London, on Thursday, January 20th, 1921, the Right Hon. Lord Weir presiding.

The CHAIRMAN, in introducing the lecturer, said about 27 years ago Lord Montagu adopted a young and very delicate child. On its upbringing and its introduction into the British industrial world he devoted a large part of his time and a very considerable measure of his wonderful energy and enthusiasm and played a very prominent part in fostering the recognition of the child as a useful factor in industry and obtaining liberty for the infant to run about our roads and highways. He (the Chairman) did not think he neglected any opportunity of reading papers before the different societies, forecasting the wonderful manhood which would be achieved by the community if it would support and encourage the industry. To-day he had the proud satisfaction of looking at his one time infant prodigy. By that prodigy he (the Chairman) meant the petrol-driven passenger and commercial vehicle. He was responsible for an entire revolution in our system of transport, which was the basis of a strong and healthy British industry. Since the beginning of aviation Lord Montagu had adopted it as another child, and one with infinite possibilities. He had been one of the strongest supporters and most active workers in the development of aviation. He was now going to give them the pleasure of hearing his views on the more commercial aspect of the different forms of transport. Lord Montagu was a founder of the Society and had always been one of its strongest supporters. To-night it extended to him a very hearty welcome.

Lord MONTAGU OF BEAULIEU then delivered the following lecture:—

A COMPARISON OF THE COST OF TRANSPORT AND TON-MILES BY LAND, SEA, AND AIR.

All methods of transport must be judged by their cost of operation and the revenue they produce, and the comparison, therefore, of the cost of ton-miles provides a useful but not the only basis from which conclusions can be drawn as to the efficiency and utility of such services. Vehicle, train, ship, or air miles and their cost must also be considered as well as ton-miles, and above all the factors of speed and the completeness of the service from the point of view of the user must be taken into account.

We have seen during the last few years attempts made to bolster up certain methods of transport on the ground that they are beneficial as a whole to the community, to special trades, or to the welfare of particular places or classes. But sooner or later the practice of subsidising any kind of transport out of taxes or rates, or out of the proceeds of other allied concerns, will have to be recognised as unsound, though there are exceptional cases where one service is naturally complementary to another kind of service, and in the end the methods of transport that will survive will be those that can stand upon their own bases. It must be remembered, however, that during the early stages of any new kind of business or of transport, such as transport by air, it may be advisable from a national

point of view to give definite help in order that it may survive its initial difficulties. But I desire to impress upon my audience at the outset that though help may be given for a definite purpose or for a stated time in the preliminary stages, in the case of air transport it cannot, like other means of transport, survive eventually unless it earns sufficient revenue to pay for the cost of operation plus a reasonable interest on the capital involved.

The actual cost of transport does not matter, or if one form of transport is more costly than another, if the particular type has some inherent qualities which appeal to the public who use it and will pay enough for its use. To take examples, it may be said that two such qualities are (*a*) high speed such as air transport can provide, and (*b*) comfort and convenience in trains or ships for which passengers will pay beyond the mere payment for conveyance. To deal with the first of these, speed much in excess of the normal or most economical speed always costs a good deal more whether by land, sea or air. From the scientific point of view this must be so, because increased speed by land, sea or air involves more resistance to travelling through the medium such as air or water as well as greater friction in the propelling and power-transmitting machinery, demanding therefore more expenditure of power. In addition, in some cases increased speed means the employment of more skilled and more highly paid labour, though not necessarily of a greater amount of labour. Speed, let us remember, is a comparative and not an exact term and what is called speed varies much in rate of miles per hour in each element and in each kind of transport. The fastest sea speed, for instance, is a speed considered moderate on land, while the fastest land speed to-day is slow compared with the latest achievements of the airplane.

In the case of air transport to-day, high speed compared with other means of transport is the greatest asset, and for certain goods and passengers this kind of high speed will always be in demand. Moreover, the longer the journey the greater the advantage conferred by high speed. Nor do ordinary economic conditions, as expressed in formulas such as the cost of ton-miles, apply in many cases. The fastest trains, motor cars and liners are largely used because they save time, and time to many persons means the capacity of making or saving money. In other words, the saving of time in transit is willingly paid for by a section of the public, and the minutes, hours, or days saved by high speed can be sold in the open market at varying prices, in addition to the right of transportation between the points of departure and arrival. For instance, the route from England to India direct by airship is about 3,600 miles, and at an average speed of 50 miles an hour this journey would take about 72 hours or three days, while the fastest journey by the existing overland and mail ship route to-day takes 15 to 16 days. Such an airship service, which as a matter of fact is quite a practical proposition to-day from a mechanical and aerial point of view, would save about 12 days over any existing route to India, and these 12 days would be worth to certain passengers so much for money making, important political work, urgent private affairs, or other special reasons. In the case of fast transport, therefore, particularly in air transport, the public authority or the company providing the transport is really selling not only the right to the individual to be transported from A to B, but a certain saving of time in comparison with the next most rapid means of conveyance. This is the real reason why high speed is commercially valuable and will always be valuable. Also, in addition to this, there is always the common human characteristic of impatience and intolerance of slowness, and the desire to get to a destination quickly, which is always manifest in all energetic and alert nations and individuals. On the other hand, delay and slowness is immaterial to certain persons and races either in the case of those whose mental development as a rule is not very high, or whose habits and circumstances are such as to make the passing of time an immaterial factor in their lives. This latter reason is exemplified in India where the majority of Indians prefer to travel by slow trains and slow road conveyance, because they are never in a hurry. In

addition the traveller by train appreciates a comparatively comfortable seat and protection from the sun or rain for the longest time possible and express trains arrive too soon for such individuals. Flying is admittedly the fastest method of transport, and it is difficult for the human mind to think of any faster method of transport. Eventually, therefore, Governments or commercial companies should be able to sell in future transportation by air chiefly because of the saving of time which great speed is able to achieve.

I have devoted these opening sentences to a brief discussion of the question and value of speed, because in considering any kind of transport statistics, especially ton-mile statistics, it is not only the cost per mile or per ton or per passenger which must be considered in comparing the different methods of transportation, but as I have already pointed out, the value of speed as well if a useful comparison is to be made out.

We will now consider first of all the cost of ton-miles by land transport. Any consideration of horse transport I will omit for it is dwindling fast and forms less than 10 per cent. of the passenger and freight traffic of our streets and roads to-day. It is admittedly, however, for certain purposes and for short distances a cheap form of transport. Also I will not touch on the question of tramways as with very few exceptions they convey passengers only and only operate for short distances. They are also becoming less important in comparison with other forms of transport. But in nearly all forms of land transport the cost of labour is now such a large proportion of the total cost of operation that those methods of transport that employ the least labour are those which now and in the future are likely to be the most popular and the cheapest. The expenditure of more mechanical power in the conveyance of passengers or goods is of comparatively little importance to-day compared with the extra cost of the labour bill, and an increasing tendency, therefore, is seen in every direction in regard to ships, railways and mechanical road vehicles to replace human labour by automatic devices and mechanical means. On ships the substitution of oil fuel for coal, also making a ship independent of coal strikes, is one of the manifestations of this tendency, while on railways the employment of automatic signalling, larger locomotives, auto-transporters of every form, and escalators for passengers are all methods of reducing the cost of labour needed per ton or per passenger moved.

As regards road transport, the cost of labour per ton-mile is high and the trailer is coming more and more into favour as economical of power and as saving labour. Constant strikes and the raising of wages time after time have also disorganised the economic conditions of various forms of transport, and in some cases made them so costly that the economic limit has been reached and bankruptcy stares some concerns in the face. The loss on the tramway systems of this country reached a figure of over three millions sterling last year. The public refuse to pay more and the receipts are in some cases less than at the lower fares. Such a condition of affairs cannot last long. Railways in general also are by no means solvent concerns in the majority of cases.

As to the air, which we are considering specially to-day, aviation has some undeniably inherent advantages. There is, for instance, no permanent way to keep in order, and the necessity for the employment of a large amount of labour exists chiefly in the case of the dirigible. No practical mechanical means has yet been generally adopted for releasing or mooring an airship without the help of a considerable number of men. But developments are proceeding which will reduce certainly a proportion of the expense of manual labour.

I will now come to the actual cost of ton-miles so far as I have been able to obtain statistics, and in putting before you the following figures I must thank various individuals and firms for the information they have given me.

To deal with road transport first of all. The cost of mechanically propelled vehicles should be based on an estimate of a maximum of 250 out of the 300

working days per annum, that is about two-thirds of the total days of the year. Taking the commonest type in this category, the petrol operated vehicle, carrying 3 to $3\frac{1}{2}$ tons useful load, I find on collating many statistics that the average cost of operating these, on the basis of a run of about 40 miles a day, is about 2s. per vehicle mile, or a cost of about 8d. per ton-mile. This charge, it must be remembered, generally includes the wages of one or two men, who help to load and unload, in addition to the actual conveyance of the load from door to door, and not only from station to station as in the case of the railway or from port to port in the case of ships. The operation of a 3-ton steam vehicle on the same mileage basis I put at about the same ton-mile cost, namely, 8d., but in this case the saving in fuel cost is balanced by high mechanical repairs owing to the existence of the boiler, furnace, and water supply system. The cost of the smaller 30cwt. van can be put at about 1s. 6d. a mile or about 1s. a ton-mile. This sort of vehicle is chiefly used for parcel delivery or light goods. When large fleets of motor lorries or vans are used the fixed and overhead charges are of course less averaged over a considerable number of vehicles, and again, liquid fuel is bought cheaper in larger quantities, and repairs done more cheaply at home in most cases. As to the cost of the electrically propelled vehicle, the simplicity and handiness of these vehicles, added to their cheapness in operation, have made them very popular of late. Taking electric current at the high figure of $1\frac{1}{2}$d. a unit or about double the cost in large quantities before the war, the expense of each vehicle mile works out with a 3-ton lorry at about 1s., or about 4d. a ton-mile. The limited radius of action—about 50 miles on one charge—is an inherent drawback for long distance work. But for collection and distribution in towns no transport is cheaper than the electric vehicle.

Recently I was able to investigate the figures of a certain County Council showing the cost of operating 16 mechanical vehicles used for road repair—three petrol and 13 steam operated. The ton mileage in this case worked out at a cost of 14.083d. This cost is unusually high and will be reduced no doubt before long. But such work as was done was somewhat intermittent and the vehicles necessarily stood idle for considerable periods and when on the road covered as a rule only short journeys.

In this calculation of costs I include depreciation, insurance, rent, fuel, oil, waste, grease, wages, bonuses, repairs and renewals, but no interest on capital.

As regards the lighter form of transport, the private car, char-a-banc and the motor bus, it is difficult to transform passenger service into ton-miles, though as an average about 15 passengers go to the ton. But it may be stated that the present cost of conveying passengers by road by means of motor bus or the char-a-banc varies from 15d. to 24d. a mile, and assuming 16 passengers, an average of two-thirds of a full load (24 passengers) the cost works out at 20d. or $1\frac{1}{4}$d. a passenger mile. If the weight of the vehicle, $3\frac{1}{2}$ tons, be included as well, then the cost of the ton-mile will be much reduced. In the case of private cars, assuming the average running cost of the moderate powered car without a chauffeur as about 6d. per vehicle mile, at this cost at least four persons can be conveyed, which would mean a cost of about $1\frac{1}{2}$d. per mile per passenger. The cost of larger cars run with paid drivers is now anything between 8d. to 1s. 6d. a mile.

As regards railways, the rise in all outgoings, especially in rates, taxes and labour has been so great of late that it is difficult to give accurate particulars. I am informed on good authority, however, that about 1.6d. per ton-mile was a fair figure till a year ago. But this figure does not include recent rises in costs or labour. The expenses of collection and delivery also in the case of goods not carried in large direct consignments which have also to be added to this 1.6d. so far as the real cost for purposes of comparison between origin and destination has to be ascertained. Two most serious features in railway expenses are the rise in labour and local rates, and British railways will have to pay upwards of

£10,000,000 this year for this latter charge. Owing to this and other causes it is probable that the cost of transport by rail will continue to rise. Indeed, an average of about 2½d. per ton-mile will probably not be an excessive calculation, a figure which would have been thought impossible to charge as an average a few years ago. Considering that this figure only includes the bare cost of transit between station and station, and except very rarely from origin to destination, it is probable that the tendency of all kinds of traffic, except coal, iron and heavy goods in large quantities, to leave the railways and go on to the road will become more pronounced as years go on. Then again, a new, disquieting and expensive feature is the evil of stealing and pilfering which is now a very common complaint, increasing the average cost of freight to the merchant or consignee. It should be remembered that the railway and the ship only convey from fixed points of collection to fixed points of delivery, and not from the point of origin to the ultimate destination. The exact theoretical cost of conveyance is not therefore always the only test by which the trader judges and decides what kind of transport to use.

As regards transport by sea, this is naturally the cheapest of all kinds of transport. There is in this case, like the air, no permanent way to maintain, and the tonnage of goods or number of passengers carried at the same time by the same power and by the same labour is as a rule infinitely greater than by any other means of transport. In the form in which I have been able to obtain the cost of ocean transport, I have had to take into account the gross weight of the steamer besides its contents, for it is almost impossible to give the cost of the conveyance of cargo and passengers apart from the ship with her engines, coal, stores and all equipment. And as regards the cost of a voyage, this too must include the time and expenditure not only on the voyage, but in ports of call, allowances for delays at destination, as well as for loading, storing and discharging goods and the cost of depreciation and insurance. I have obtained a few typical figures of voyages from London to the East, returning to London. But as the cost per ton-mile by sea is such a small fraction of a penny, the following costs are shown per 100 ton-miles, calculated on the gross weight of the steamer and its contents.

Route.	Cost per 100 ton-miles. Fuel. Pence.	Other items. Pence.	Total. Pence.
London-Australia (via Canal)—			
16 knot mail steamers ...	3·3	3·3	6.6
14 knot intermediates ...	2.4	2.7	5·1
London-Australia (via Cape)—			
Cargo liners	1.6	2.2	3.8
London-Bombay (via Canal)—			
16 knot mail steamers ...	3.8	3·4	7·2
London-Calcutta (via Canal)—			
14 knot intermediates ...	1.4	3.6	5·0
London-Japan (via Canal)—			
12 to 14 knot intermediates ...	2.9	2.9	5.8

The estimated cost, on the other hand, of conveying saloon passengers per ship mile, exclusive of food, but assuming that the whole accommodation for passengers is occupied through the entire journey, is given below:—

Routes (via Canal).	Pence.
London-Australia, mail steamers	1.44
,, intermediate type	1.11
London-Bombay, mail steamers	1.80
London-Calcutta, intermediate type	1.20
London-Japan, intermediate type	1.42

At $1\frac{1}{2}$d. average per passenger per mile and allowing 15 passengers to the ton, then the cost of ton passenger miles is about $22\frac{1}{2}$d. a mile, about the same figure as a motor bus or char-a-banc.

ROUGH ESTIMATED COST OF CARRYING CARGO PER 100 TON-MILES EXCLUSIVE OF LOADING AND DISCHARGING EXPENSES.

	Pence.
London-Australia, mail steamers	10.1
,, intermediate type	8.2
,, cargo liner (via Cape) ...	6.7
London-Bombay, mail steamers type	12.0
London-Calcutta, intermediate type	9.7
London-Japan, intermediate type	9.8

It should be noticed in these statistics that no allowance has been made for interest on capital, which in the case of shipping companies varies from a comparatively low rate which has to be paid on debentures, to a high rate in some cases on ordinary shares where there is not the same security. It is clear from the above figures that the cost of ton-miles by sea is much less for goods than the cost of ton-miles by land, or indeed by any other method of conveyance, so far as can be ascertained at present. But a port, like a railway station, is seldom more than a point of distribution and collection, and I must once more remind you that "origin to destination" should be the ultimate aim and motto of all transport.

In regard to the cost of conveyance by aircraft, I have been in communication with some of the firms who have been conducting recently regular commercial services by airplane and find that their statistics vary a good deal. Lately, at the Air Conference at the Guildhall, Mr. White Smith, whose opinions are entitled to much weight, stated that a machine could be flown between London and Paris at about 38d. per airplane mile. The D.H.18 has lifted and flown with a weight of 2,200lbs., but with a D.H.18 designed purely for goods carrying, and at the reduced speed of 75 miles an hour, the machine would lift probably as much as $2\frac{1}{2}$ tons, or well over 5,500lbs., and the cost per ton-mile would therefore be correspondingly reduced. This figure of 38d. has recently been thought too low and later and perhaps safer calculations place the cost at about 40d. per machine mile. It is clear that in this case there can be no competition with other older methods of conveying heavy goods in bulk. But with passengers, mails and valuable and special freight the outlook is promising. I am inclined myself to think that the cost of airplane transport at the present moment is in the neighbourhood of 44d. per ton-mile, if a reasonable profit is to be included and all risks provided for. At this price the aeroplane can only compete successfully with existing transport because of its speed either over land or sea. As I have said before, speed is a quality which the public are willing to pay for, and speed is the commodity which sellers of air transport will find most saleable.

We now come to airships. In the case of the airship of the large type, which recently flew from Great Britain to America and back, the cost was ascertained to be in the neighbourhood of 23s. 6d. a mile flown. To take the concrete case of England to Cairo and India, and allowing 50 hours for the journey to Cairo and 50 hours on, the expenditure comes out according to Air Commodore E. Maitland at the following figures:—

	s.	d.	
Interest on capital expenditure ...	7	0	per mile over land or sea.
Cost of operating the airships ...	23	5	,, ,, ,,
Cost of running the bases	11	0	,, ,, ,,
	41	5	

Or an "all in" cost of 497d. per mile made good over the ground. If the airship could carry, as a conservative figure, 15 tons of commercial load for a journey occupying 50 hours, this would make the "all in" cost per ton-mile $35\frac{1}{2}$d. for such a journey. Not a formidable figure in comparison with other methods of fast transport.

Allowing seven passengers to the ton, which for practical purposes amounts to each passenger being allowed 1cwt. of luggage free, and one ton of mails at 6d. per oz. for each stage of 50 hours, the following table is of interest:—

	Airship.			Steamer.	
England to	Approximate Time of Transit.	Mails (1 ton carried).	Passengers.	Approximate 1st Class Steamer Passenger Fare.	
Egypt ...	$2\frac{1}{4}$ days	6d. oz.	£50	£45 to £50	Now increased about 20% beyond these figures.
India ...	5 ,,	1s. oz.	£100	£65 to £70	
South Africa	$6\frac{1}{2}$,,	1s. 3d. oz.	£120	£70	
Australia ...	$10\frac{1}{2}$,,	2s. oz.	£190	£115 to £128	

The above figures are based on airships actually under construction (R.38 class), showing a profit of 15 per cent., and are based on the carriage of 75 per cent. of the possible passengers.

The passenger ton mileage in this case would work out at about 34d., but no doubt these costs will be reduced later on. And while the cost is in this case moderate, there would be a great saving in time on a non-stop run for at least 2,500 miles—say London to Egypt or 3,800 miles London to India.

TABLE I.

COMPARATIVE AVERAGE SPEEDS BY LAND, SEA AND AIR.

	Miles per hour. Average speed.
Land.	
Express and fast trains	40
Ordinary passenger train	25
Ordinary goods train	14
Motor car or cycle	20
Motor bus or char-a-banc	15
Motor lorry	13
Sea.	
Mail ship	16
Ordinary passenger ship	12
Ordinary cargo ship	10
Air.	
Airplanes for mails and passengers	100
Airplanes for goods	80
Airship for mails and passengers	60
Airship for goods	50

TABLE II.

COST OF TON-MILES BY LAND, SEA AND AIR.

Land.			
From station to station.			
Per train—Passengers, 15 to ton at 3rd class fare of 2d. a mile	30d.	B	
Goods, average (1919)	1.6d.	B	
From origin to destination.			
Per motor lorry—goods in not less than 3-ton lots ...	10d.	B	
Per bus or char-a-banc—15 passengers to ton	22½d.	B	
Per average motor car	8d.	A	
Per motor cycle	2d.	A	
Sea.			
From port to port.			
Mail ship	.066d. to .072d.	A	Calculated on gross weight of steamer and contents.
Passenger ship (intermediate) ...	.050d. to .058d.	A	
Cargo liners	.038d.	A	
Air.			
From aerodrome to aerodrome.			
Airplanes for mails and passengers, D.H.18	30d.	A	
Airplanes for goods, D.H.18 (special type)	14d.	A	Estimated.
Airships for mails and passengers, say 10 tons in all ...	36d.	B	
Airships for goods (R.38) ...	35½d.	B	Excluding insurance.
Airplane, 2-engine Vimy type ...	126d. per machine mile.	B	

A weight of vehicle included.
B weight of vehicle not included.

TABLE III.

TRANSPORT IN ORDER OF SPEED.

		Average speed in m.p.h.
1.	Airplane for mails and passengers	100
2.	,, goods	80
3.	Airships for mails and passengers	60
4.	,, goods	50
5.	Express and fast trains	40
6.	Ordinary passenger trains	25
7.	Motor cars and motor cycles	20*
8.	Mail or fast passenger ship	16
9.	Motor bus or char-a-banc...	15*
10.	Average goods train	14
11.	Motor lorry for goods	13*
12.	Ordinary passenger ship	12
13.	Ordinary cargo ship	10

* The road motor vehicle is the only vehicle which can collect and deliver without intermediate handling between origin and destination.

These figures show that while the cost of ton-miles may in some kinds of transport and for some kinds of freight be a criterion of some value, it is not the only basis of comparison. In other kinds of transport and in the case of freight which has to be collected and distributed in small or comparatively small quantities, it is of little or no value as a guide to either what the public will pay or the traffic will bear. Speed also is an increasingly important factor both in conveyance from origin to destination, as well as from station to station or port to port. Motor transport provides for this, and on long journeys over land or sea by the airship and airplane will equally provide speed. For ascertaining the cost of operating any system of transport, vehicle, train, ship and machine miles divided into the total expenditure will give results in some ways more valuable than ton-miles divided into the total outlay. When, therefore, comparisons are made of various kinds of transport it is first of all necessary, as I have shown, to ascertain exactly what exact services are rendered by the so-called kind of transport, and whether the passengers or freight conveyed demand high speed or special comfort, or conveyance to fixed points only, or to actual destination with no intermediate handling. There can be no question that the public in a country like Great Britain with a number of convenient ports all round the coast and well provided with roads, can with difficulty be forced to pay charges beyond a certain economic figure for railway carriage except for a few special heavy and bulky kinds of goods.

Given free trade in transport, a fair field, and the kind of transport best suited to each kind of trade will win. But air transport will have to fight for its life for some time to come. It is admittedly not yet a cheap form of transport, but it is very speedy, and its main drawback is that at present only short journeys are attempted, such as the cross-Channel, which are not long enough journeys to bring out the advantages of high speed. The net saving of about three to four hours between London and Paris is not sufficiently attractive. But from London to more distant points, such as the Riviera, Italy, Egypt, Algiers, Morocco, and eventually India, are journeys in which the saving of time would be so great as to tempt passengers in a hurry to brave some discomfort, the greatest of which is noise, and to pay a great deal per ton or passenger miles accomplished at say 100 miles an hour. If I were a capitalist or inventor, I would rather have money in a London-Riviera-Algiers-Morocco Transport Co. than in a London to Manchester, Paris, or Brussels Company. There can be no effective competition with conveyance by air on these long distance journeys, and the great saving in time for mails should appeal—though it has not as yet—to the Post Office authorities of every country. And for these long distance journeys I feel sure that the airship rather than the airplane is the best method of transport.

Finally, I may be excused for asking whether the world in general realises the great political as well as economic importance of transport. Lack of roads was and is the sign of a low form of civilisation. It was the most potent cause of the success of the Red Revolution in Russia. It is the chief cause of scarcity and famine in the towns and of isolation in the country districts in Russia to-day. The Government of a country cannot govern or carry on effective administration without passable roads along which troops, people, posts, supplies, and news travel. The greater the transport facilities the easier can social difficulties be ameliorated and overcome. All kinds of transport are necessary for the increasing commerce of the world and air transport will have to bear its share before long in conveying its special kinds of freight. No civilisation can continue to exist without healthy transport conditions, and subsidies and Government control are not healthy symptoms at the moment, and should be got rid of at the earliest possible opportunity. In this, though necessarily brief and condensed lecture on the cost of transport, I have been unable to touch on any but the most prominent features. But the subject is one worthy of concentrated study, and if I have been able to stimulate thought in others I have achieved my object and I hope been able to interest my audience this evening.

DISCUSSION.

The CHAIRMAN said Lord Montagu had clarified many of the vital commercial factors affecting the future of air transport. If he (the Chairman) were right, Lord Montagu's main object in the paper was to show the immediate possibilities and the cost of air transport in the correct sense of proportion to the cost of other forms of transport, and he asked them to look the situation straight in the face. The figures for aircraft appeared very disadvantageous from the commercial point of view, but he wanted to endorse very strongly Lord Montagu's important qualification when he pointed out that exceptional performance, say in the form of speed, while it always entailed additional and exceptional cost, warranted one in assuming that an exceptional price could also be obtained. In Atlantic travel in pre-war days the speed of the "Mauretania" assured a full ship at almost premium rate. To take another example, where speed was not defined, on the German Sud-Amerika Line they gave the most extreme degree of luxury, and that commanded a very big premium, because it was exceptional. He was glad Lord Montagu emphasised so strongly that commercial aviation depended for its ultimate future on its own sound economical performance, with no adventitious aids such as subsidies which were not justified except in the initial stage of the development. They were largely justified there from the national defence point of view, and, in that connection as Chairman of the Advisory Committee, he was naturally gratified that the Government had accepted their recommendation, but infinite harm had been done by the delay of the decision. They owed Lord Montagu a great deal for pointing out a matter which he (the Chairman) thought was new in connection with transport, and that was the changing incidence of labour cost on the cost of the different forms of transport. It deserved very careful consideration by transport authorities, and its importance was very well shown when Lord Montagu definitely suggested that a large proportion of the railway traffic must leave the railways and come on the road. That was a bad look out for the railways, but when one existing way of doing a thing was put hard up against keen competition the scientists and the organiser came in and found a way around it. Perhaps the best example was electric light. That simply helped the gas companies. The gas companies did better than ever. He was rather of opinion that there would be a slight reaction in that tendency, because the very much needed increase of efficiency in the method and process on the railways was absolutely bound to take place. Finally, he would like to say something with more confidence and more optimism on the immediate future of commercial aviation, but it was not very easy. Without doubt the figures of performance of the cross-Channel services during 1920 furnished strong ground—legitimate ground—for optimism, but, unfortunately, the pressure of to-day's financial and industrial conditions handicapped realisation of these immediate possibilities. But they must all be of good cheer, for stability and confidence would be regained in financial and commercial services. When that position was regained they could bring the full weight of public opinion to bear on the new form of transport and encourage the re-awakening of enterprise. The figures in the paper dealing with airships were very hopeful. He would like to ask whether these were merely operating costs or whether allowances were included for the outlay on the sheds and aerodromes, because that was a big factor in connection with airships—the building of the sheds, the interest on the ground and the capital cost of the sheds were a vital factor.

Mr. H. WHITE SMITH said he would like to refer to a figure of his which Lord Montagu quoted as 28d. per aeroplane mile. If he looked at his (Mr. White Smith's) paper he would see the figure was 38d., practically the same as Lord Montagu quoted (44d.). The Lecturer gave for aeroplanes for mails and passengers 30d. He (Mr. White Smith) thought it should be somewhere near 43d.

But perhaps Lord Montagu would be able to explain how he arrived at his figure. In certain cases he had included the weight of the vehicle. For commercial purposes the weight of the vehicle obviously could not be included. The weight of a train could not be included in calculating the cost per ton mile of goods carried. To bring all the costs to a common basis, the weight of the vehicle would have to be cut out in every case. Lord Montagu had very properly emphasised the question of point to point movement of goods and passengers. It would be interesting if calculations could be made as to the cost of handling goods in the form of transhipment in connection with ships, railways and other modes of transport. Even motor transport was not always point to point, strictly speaking. Goods were sent from a warehouse, perhaps by motor vehicles to start with, and then carried on railways and on ships, and at the docks it was handled then by railways again or motor vehicles, and there was a great accumulation of handling charges during transit. If the handling charges were added the ton-mile total would come to substantially more than any of the figures they had put before them. There was the obvious advantage in air carriage that if the goods were kept on the same aircraft the large mass of these handling charges was saved. There would still be the cost of the initial placing of the goods on the aircraft and of taking it off, but not the intermediate transhipment, of which there was so much in the ordinary transport. The true comparison was therefore more favourable to aircraft than appeared at first sight.

Another point that came out was that each form of transport had its own sphere. He doubted whether the air would ever entirely take the place of either of these other kinds of transport. It would be supplementary to them. But in order that it should take its proper place there would have to be considerable reductions in cost. He agreed that speed, which had the effect of saving time and expense, was of great value, and that it must be brought into the calculation in arriving at the cost, but to promote greater use by the public costs would have to be brought down. He agreed with Lord Weir that airship terminal charges were a very important item. There were obvious advantages in the use of airships for very long journeys, but it was rather difficult to see the immediate development of them. The question of finding the capital cost of constructing airships of such design as would enable them to be run commercially was so considerable that, with the financial conditions which seemed likely to obtain for a number of years, it seemed difficult to see where the capital was to come from. The experiments that had been carried on were most useful in showing how far the estimates of cost per ton-mile could be borne out, but it was difficult to see into the future for some years to come. In most of the other forms of transport, whether tramways, motor buses or railways, the costs all seemed to be going up, and they would be handicapped to that extent, as with aircraft the tendency was the other way, and he thought it would continue. The design was improving, the engines were being improved, and he thought in the not far distant future aircraft would be running at costs which were really quite commercial.

Mr. F. Handley Page endorsed what had been said in regard to the necessity for air transport to stand on its own results rather than on Government support. If the future of air transport depended on Government subsidy a large financial return could never be expected. If large dividends were earned, and that result was obtained by Government subsidy, there would be an immediate move to abolish the subsidy or nationalise the industry. Eventually, if air transport was going to pay it must depend on running at such a price that its costs were a great deal less than the revenue. The margin of profit, too, must be sufficient to enable canvassers to be employed in selling air transport. As an illustration, if a typewriter were being put on the market, the works cost was only 45 per cent. of the selling price, the remaining cost being that of selling the article. At present one must have canvassers to sell air transport, whether of goods, passengers or mails, and that cost had to be borne in the cost of running the service.

A point that was sometimes overlooked was that service to the public meant more than merely flying from point to point and having a fine machine, beautifully tuned up and an engine running perfectly. It embraced quick delivery of parcels, which entailed such mundane matters as cash-on-delivery. In one case his firm had a parcel which came by air and certain money had to be collected on it. The cheque arrived three or four days later and the consignee wrote saying if that was the quickest way parcels could come by air from the Continent he would have them sent by wheelbarrow in future. The reason for this delay had nothing to do with air transport, but with the ordinary business feature of completing the transaction.

He was amazed to read in that week's "Engineer" an article by a gentleman who called himself "A Pioneer of Aviation," in which he emphasised the view that it was fear of accident when travelling by air that retarded the progress of aviation. That was nonsense. His undertaking had the misfortune of having an accident at the close of last year resulting in the death of some passengers, but it was a remarkable fact that the passengers had not fallen off a bit since that time, allowing for the fact that in the winter there were, naturally, fewer passengers than in the summer.

To make air transport a success, however, the cost of travel must come down, and that could only be achieved by having aeroplanes that could carry greater loads with the same engine power and operate more cheaply by having better standardised machines with fewer working parts and simpler construction all the way through. The time that was now available for investigation of fundamental aero-dynamic processes would probably result in such machines being evolved. The price could then probably be reduced to half or a third of what was charged at present. Success in the reduction of cost depended entirely on the aircraft designer in bringing down the first cost as well as the running cost of the machines.

There was no specific mention in the paper as to the life of an airship. One heard that after the trans-Atlantic trip the large airship used had little life left in it, the rivets being all so badly strained. The depreciation cost depended on the life, and if, as Mr. White Smith said, the capital cost necessary for airships would make their use in the next few years impossible, it seemed that the money spent on experimental airship services could be better given to the aeroplane service, with more immediate profitable result.

Colonel A. Ogilvie thought it was rather difficult to arrive at any figures now with regard to the initial cost of airships, because of the very small numbers of any particular type that had been produced. If true figures of the Zeppelin construction could be got from Germany we might get a different view of the question. There they laid down a dozen or so of the same type and turned them out in a month or so and the initial cost might be a very different thing from our present machines, which were made one at a time and took a year or so to complete.

It seemed to him that there was much more possibility of improving and reducing the running costs in the case of the aeroplane than in that of any other kind of vehicle. The railway costs could not very well be less, and road vehicles had always to contend with the great expense of tyre upkeep, and their engines were not likely to be improved to such an extent that the cost would come down greatly. But there were many more possibilities in the aeroplane which should bring down the cost greatly. He had recently been working on some figures for the resistance of machines at top speed, and the amount of power that appeared to be wasted was remarkable, although he thought the present designs were as good as could be done with the present knowledge. The wings absorbed a great deal more power than they should do or than they would do if reduced in size, and if it were not for the difficulty in landing, the resistance of

the wing might be reduced to a half or a third of what it was at present. One had to compromise between the difficulty of landing and the reduction of the wings, but only a relatively small improvement was wanted there to put a completely different complexion on the matter. A large quantity of power was wasted in pushing the undercarriage along, which was of no use in the air, and an extraordinary percentage of the H.P. went in pushing the fuselage, which was an awkward shape. The proportional resistance of a fuselage and an airship body was about four to one. The airship was four times as good a shape as the other. Such considerations made one think that in a little more time, with a little more research and experiment, the cost of aerial transport would be considerably reduced.

Sir Charles Bright said the paper, the first of its kind, was extremely useful and would long remain so, although one hoped the figures would get out of date before long. What was needed to bring aviation to the fore was to focus all their strength on getting it taken up in far-reaching and low populated countries such as Australia, where there were comparatively few railways or good main roads. In cases of this kind aviation should be of immense value for all those concerned in agriculture of one kind or another as well as for business people generally. It should also be invaluable as a means of direct personal communication for diplomatic purposes—in a way that could never be achieved by telegraphy of any description.

Lord Montagu, replying to the discussion, said the airship costs included the following costs, as set out by Air-Commodore Sir E. Maitland in a recent paper: The cost of the airship, the cost of the base, the operation of the airship, maintenance, depreciation, the cost of the crew, fuel, running the base, and so on. As stated in his (Lord Montagu's) paper, interest on capital worked out at 7s. per mile made good, the cost of operating the airship at 23s. 5d. per mile and running the bases at 11s. per mile. The life of an airship should be divided into the fabric, the engines and the hull, and the fabric should be sub-divided into the outer cover and the gasbags. The life of the outer cover might be taken as one year, with 2,500 hours flying, the gasbags or ballonets 2½ years, and owing to the fact that airship engines were not run at their full power he also gave them a life of a year, or 2,500 hours flying. They did not know the life of the fabric, except that in the war our airships ran, roughly, three million miles and they had not yet been able to ascertain that they showed any sign of weakness. There was no tiredness of the duralumin, this being due to the fact that there was very little vibration. He apologised to Mr. White Smith regarding the figure of 28d. per airplane mile. That was a printer's error. It should have been 38d. He had to put in the vehicle weights as the shipping people said they could not give the cost without including the weight of the ship. In the paper as he had corrected it he had put A against the figures which included the weight and B against those which did not. He would give the figures of the cost of airship service between England and India. Interest on capital expenditure and reserve fund at 15 per cent. £156,750, or say £157,000, cost of operating airship, as previously stated, 23s. 5d. a mile flown, annual cost of running English base £116,700, running Cairo base £116,700 and running mooring station at Karachi £12,000, making the total £245,000.

In reply to a question as to whether the Zeppelin cost anything like that, the Lecturer said Sir E. Maitland thought that was so, and they must accept him as knowing what he was talking about. These figures were based on airships actually under construction, such as the R.38, and on carrying 75 per cent. of possible passengers, and 15 per cent. profit. Colonel Ogilvie suggested that we had not enough experience to base our calculations on. Our "Blimps" and different airships ran over three million miles during the war with very few accidents, and a good deal was learnt from it.

In reply to the Chairman, the Lecturer agreed that the Zeppelin costs were much lower than our airship costs. When he investigated them some five years ago big Zeppelins cost from £120,000 to £130,000.

A hearty vote of thanks was accorded to the Lecturer on the motion of Mr. WHITE SMITH, who said he had always been a pioneer. One remembered the splendid work he did in connection with the motor car industry, and it was most valuable to have men like Lord Montagu interested in aviation and pleading its cause in the House of Lords and Government circles. The paper would be most helpful to people who were trying to think of aviation commercially.

On the motion of Colonel OGILVIE, seconded by Lord MONTAGU, a vote of thanks was also passed to the Chairman who, in acknowledging the compliment, asked Mr. Handley Page whether he knew anything we were able to do as quickly as we did it in 1913, and the answer was "Yes, talk."

Written contribution from Flight-Lieutenant J. E. M. PRITCHARD: I feel that Mr. Handley Page's contribution to the discussion, especially with regard to his technical statement as to the state of R.34 after her return from the Trans-Atlantic flight, calls for a definite reply.

Before carrying out the flight to New York and back, a distance of over 6,000 miles, R.34 also flew several thousand miles in the course of her preliminary trials, besides carrying out a flight into the Baltic of over 1,200 miles. From the time R.34 was commissioned till her return from America, no special structural or machinery overhauls were carried out, with the exception of the substitution of one new engine in place of an engine which broke down. A short time after R.34 returned from America, she flew from Norfolk to Scotland and again without repairs flew from Scotland to her present station in Yorkshire.

The ship is now in thoroughly good condition, and the only repairs to the structure which it was necessary to carry out cost under £100. These structural damages were almost entirely caused through rough handling while refuelling in America, and not to any strains incurred during the flight. By far the greatest overhauls necessary were those to the machinery installation, the engines in particular. These overhauls were, however, by no means abnormal. In connection with overhauls to machinery, it is interesting to note that airships at present use aeroplane engines. In airships, however, these engines give greater reliability, because they can be run at reduced power.

A large modern rigid airship carries in the order of 16lbs. of useful load per h.p., while it is understood that the average aeroplane only carries in the order of 3lbs. per h.p. Thus, taking the worst view as regards the airship, the machinery items in the airship should only require one-fifth as much overhauling for transporting unit commercial load unit distance as is the case with the average aeroplane.

At present, and I fear for some time to come, any clear conception of the lines along which aerial transport will develop in the future, is unlikely. At the moment, the general public is by no means universally convinced as to the need of aerial transport at all, and those of them who do believe in this form of transport have no clear view as to which type of craft is most suitable. In this unavoidable state of confusion, it is in my opinion most regrettable that Mr. Handley Page, who is admittedly an expert in aeroplane transport, should quote rumours about airships, especially when these rumours do not happen to be true, as, owing to his eminence in aeroplane matters, his opinion with regard to airships would tend to carry a certain amount of weight with the general public.

Structural reliability is, as Mr. Handley Page states, of great importance, and I would like to quote two examples of airship reliability, one of a non-rigid, "C.9," used during the war, the other, the German rigid airship "L.14." (Unfortunately, we have not had sufficient flying in this country yet to wear out a rigid.)

"C.9" was in commission two years 75 days, her time in the air was 2,500 hours, giving a flying average of three hours six minutes per day for the whole life of the airship.

"L.14" was commissioned in August, 1915, carried out a number of raids over this country, and a large amount of patrol work. In 1916 she became, owing to obsolescence, a training ship, and flew more or less continuously till the end of the war. When inspected in Germany soon after the Armistice, this ship, although she had flown regularly during her three years' life, showed no sign of structural degeneration.

With regard to general aerial transport considerations, I would like to point out that the rigid airship has only been seriously recommended for long-distance flights. Although rigid airships have from time to time carried out safely long-distance flights without any special discredit, it has been impossible in this country to carry out regular demonstration flights over a long route for the simple reason that there is no rigid airship base outside this country available for the purpose. I understand, however, from Mr. Handley Page, that there is no such difficulty in the case of aeroplanes, and I would be glad if he would explain why it is that aeroplanes are not now carrying out regular flights between this country and, say, Egypt.

For short-distance flights, however, there is very great doubt as to whether there is any reasonable amount of freight available for aerial transport, and the results obtained on the London to Paris aeroplane service, although this worked with wonderful regularity and punctuality, tend to confirm this view.

In the case of long-distance transport, there is no doubt that the freight will be available for any form of aircraft which can fly with the necessary regularity and safety, if it can cut down the time taken by the existing means of sea transport to one-third. This can, in the opinion of airship experts, readily be done when the necessary base facilities outside this country have been provided, mooring arrangements slightly improved, and certain improvements which are clearly in view in machinery and fabric carried out.

Mr. Berriman (communicated): Lord Montagu's paper deals with the vital economics of transport services. It is a subject on which it is very difficult to acquire accurate information, and the best that can be done is to examine such figures as may be made public from time to time. The most recent were those elicited by the Mansion House Conference, notably in Mr. White Smith's paper, which is referred to in Lord Montagu's text. It is customary to compare transport costs on the basis of 100 per cent. load factor, *i.e.*, that every machine flies its allotted trip every day with a full load. On this basis air transport can be made to show a very favourable return and the main point in any critical analysis is, therefore, to investigate the true nature of the probable load factor and its consequences. It is in this respect that existing commercial air services are at a disadvantage, inasmuch as temporary disablement of the transport unit inevitably represents a high percentage of reduction in the total fleet and, therefore, a considerable diminution in the load factor with a consequent relative increase in the cost of operating the reduced ton miles that remain available. When the number of units in the fleet is large, the temporary disablement of any one unit has a relatively small effect.

As things are at present, it is difficult to recover air ton miles lost by temporary disablement of one or more units. Thus, it is not yet feasible to fly at night nor is it usually practicable to extend much beyond the normal the continuous service of any one machine at the expense of its allotted time off for overhaul. The flying year for air transport is usually reckoned at 300 days, and thus far there is little, if any, evidence in support of an increased estimate. Moreover, it will be found that if an unexpected spell of bad weather should be the cause of abandoning flights during a period that is relied upon as being fine, it will be very difficult to make up the deficiency within the financial year. The effect of

these considerations on the cost of air ton miles is in some degree exaggerated by the limitations of an industry in embyro, and would decrease with development. In order to provide a numerical illustration of the effect of load factor on cost, I submit a table analysing the figure 3s. per ton mile, which was put forward by a member of the Mansion House Conference as appropriate to the London-Paris service. I do not say anything either for or against the accuracy of this figure as such, being merely concerned to show the effect of load factor upon it. I have, however, assumed that it is based on the costs of a daily round trip per machine.

For convenience, the 3s. is reduced to 3.75 pence per lb. for transport from London to Paris on a journey taken as 240 miles. This figure has additional interest also, inasmuch as it gives the cost per passenger mile on the basis of 240lbs. per passenger. The pence can also be read as pounds sterling to give the cost per passenger for this length of journey, viz., 240 miles. The cost is made up in part by overhead expenditure representing so much per day irrespective of the distance flown, and running costs representing so much per mile or rather per trip, because the mileage is determined in advance by the fact that the machine either flies a single trip in the day or a double trip in the day, but it cannot usefully fly a fraction of the journey. This is a most important point because air transport, like other transport, has for its present object to render a commercial service between two or more predetermined places, the mileage between which cannot be altered to suit the convenience of the machine. Some of the figures that were discussed at the Mansion House Conference appear to be misleading because they assessed cost per mile at an indefinite mileage, whereas, in fact, the only figures of any immediate commercial importance are those that are applicable to a particular service under consideration. If the machine flies a double trip in the day, the cost of overheads per trip is halved but the running costs are unaffected by the double journey. For short journeys, several trips may be performed in the day, but so far as the Paris service is concerned, a safe plan at present would appear to be to estimate on the basis of a single trip. Using Mr. White Smith's statistics as an approximate guide for the division of expenditure between overheads and running costs, I have taken the overhead expenditure to be represented by £3 10s. per seat per day, and the running costs by £2 per seat per trip. Thus for half the machines flying and half the available seats occupied (equals quarter total seats occupied) the cost for overheads per day is £14 per seat, but the running expenses are only increased in proportion to the number of *available* seats unoccupied which in this case is one half. Consequently, the running expenses only represent £4 per seat per trip. The total cost per trip for one trip per day is thus £18 on the basis specified. The following table has been prepared on the above mentioned basis of 240lbs. freight being equivalent to one passenger. Taking freights that are equivalent on this basis to a single passenger fare to Paris of 10 guineas, it appears that a load factor of 66 per cent. is the minimum on which the receipts will cover expenditure if the same machine only flies the single trip daily. For the daily round trip, the equivalent figure is less than 50 per cent.

	Single Trip Daily. A	Single Trip Daily. B	Round Trip Daily. A	Round Trip Daily. B
All machines flying daily and all seats full ...	£5 10	0 5½	£3 15	0 3¾
5/6 ,, ,, ,, ,, ,, ,, ,, ...	£7 8	0 7½	£4 5	0 4¼
2/3 ,, ,, ,, ,, ,, ,, ,, ...	£9 15	0 9¾	£5 7	0 5¼
1/2 ,, ,, ,, ,, ,, ,, ,, .	£11 0	0 11	£7 10	0 7½
1/3 ,, ,, ,, ,, ,, ,, ,, ...	£17 10	1 5½	£11 5	0 11¼
1/2 ,, ,, ,, ,, 1/2 ,, ,, ...	£18 0	1 6	£11 0	0 11
1/2 ,, ,, ,, ,, 1/3 ,, ,, ...	£27 0	2 3	£16 10	1 4½

A = minimum single fare.
B = equivalent rate per mile for 240 miles and equivalent rate per lb. at 240lbs. per seat.

In Mr. White Smith's paper, the costs were based on hypothetical fleets of six machines. Allowing 2,400lbs. load per machine, it is apparent that such a transport service, if devoted exclusively to goods, would have to find about 1,000 tons per annum at rates equivalent to the above in order to make a commercial success.

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Notices of the Royal Aëronautical Society.

Honorary Members.

In response to a request from the Air Ministry, temporary Honorary Membership of the Society has been offered to the following officers representing foreign governments while on service in this country :—

Chevalier W. Coppens (Belgium), Commander Evers (Denmark), Commandant Sablé (France), Major Graziani (Italy), Major-General Itamy (Japan), Captain Kobayashi (Japan), Captain de Vaisseau K. F. Sluys (Netherlands), Captain Scott Hansen (Norway), Lieutenant-Colonel Rich (Spain), Lieutenant-Colonel Mossberg (Sweden), Captain G. Hain (Sweden), Commander Tiselius (Sweden), Major Melvin Hall (U.S.A.), Lieutenant-Commander N. H. White (U.S.A.),

Elections.

The following members were elected in the various grades as shown at a Council Meeting held on April 19th :—

Fellows.—Major T. M. Barlow, A.M.Inst.C.E., C. I. R. Campbell, M.I.N.A.
Associate Fellows.—H. E. Hudson, H. J. Wilkins, A.M.Inst.Aut.E.
Members.—W. M. M. Clark, A. Newman.
Students.—J. D. Campbell, G. Chiverton.
Associate Member.—Flight Lieutenant S. T. Freeman.
Foreign Member.—Commander H. T. Dyer, U.S.N.

Council.

Sir Mackenzie Chalmers, K.C.B., C.S.I., has been co-opted by the Council, in accordance with the provisions of Rule 13, to serve as a Member in the room of Major-General Sir R. M. Ruck, K.B.E., C.B., C.M.G., who vacates his seat (with power to attend) under the provisions of Rule 18 (*d*) on appointment as Vice-President.

Donations.

The Council desire gratefully to acknowledge the receipt of a copy of "The History of the 24th Squadron R.A.F.," by Captain A. E. Illingworth and Major V. A. H. Robeson, from Major Robeson, also a copy of "Telegraphy, Aeronautics and War," by Sir Charles Bright, from the author.

Committees.

At the April Meeting of the Council the following members were nominated to serve on the Committees named. The Chairman and Vice-Chairman are *ex-officio* members of all Committees.

Candidates.—Dr. L. Bairstow, Wing Commander T. R. Cave-Browne-Cave, A. E. L. Chorlton, Captain G. de Havilland, Major H. Grinsted, Professor B. Melvill Jones, W. O. Manning, Major G. H. Norman, N. A. V. Piercy, Dr. A. J. Sutton Pippard, Flight Lieutenant J. E. M. Pritchard, J. L. Pritchard, and Major H. E. Wimperis.

Publications and Library.—Dr. L. Bairstow, Captain W. S. Farren, Captain F. M. Green, Squadron Leader R. M. Hill, Major A. R. Low, J. L. Nayler, Lieutenant-Colonel H. W. S. Outram, Flight Lieutenant J. E. M. Pritchard, A. V. Roe, Major H. E. Wimperis, and the Editor.

Finance.—Lord Cowdray, J. B. Maclean, Sir R. M. Ruck, A. E. Turner (Hon. Treasurer), and F. P. Walsh.

Representatives on other Bodies.

The following members have been appointed to represent the Society on the various bodies with allied interests :—

B.E.S.A. Nomenclature Committee.—Dr. Bairstow, Major Low, Colonel O'Gorman, Dr. Sutton Pippard, Major Southwell, and the Secretary.

Joint Standing Committee with S.B.A.C.—Chairman (*ex-officio*), Vice-Chairman (*ex-officio*), Dr. Bairstow, Wing Commander Cave-Browne-Cave, Lieutenant-Colonel A. Ogilvie, Lieutenant-Colonel M. O'Gorman, and Major-General Sir R. M. Ruck.

Conjoint Board of Scientific Societies.—Colonel O'Gorman.
Aeronautical Research Committee.—Colonel A. Ogilvie.
British Engineering Standards Association.—Colonel O'Gorman.

Library.

The following books have been received and placed in the Library :— "Meteorology," by A. E. M. Geddes, O.B.E., M.A., D.Sc., "The Mechanical Principles of the Aeroplane," by S. Brodetsky, M.A., Ph.D., "The German Air Force in the Great War," Major G. P. Neumann, "A History of Aeronautics," by E. C. Vivian.

W. Lockwood Marsh,
Secretary.

PROCEEDINGS.

EIGHTH MEETING, 56th SESSION.

The Eighth Meeting of the Fifty-sixth Session took place on Thursday, February 3rd, 1921, in the Hall of the Royal Society of Arts, London, Dr. G. C. Simpson presiding.

The CHAIRMAN said he did not think it was necessary for him to introduce Major Dobson, who would read his Paper first. He might say, however, that he was one of the very few men who were engaged on meteorology in relation to aviation before the war commenced. Throughout the war he took part in the experimental work at South Farnborough, and therefore he had had a very long connection with meteorology in aviation which would make his Paper of much more value.

Major G. DOBSON then delivered the following lecture :—

METEOROLOGY IN THE SERVICE OF AVIATION.

It has been supposed that meteorology must necessarily be of very great importance to aeronautics, and that important as it may be to, say, marine work, the services which it can render to aviation are still greater. It may not be without interest, therefore, to discuss in what ways it can be of most assistance; how an ideal meteorological service might be organised, and how far it is likely to satisfy the demands made upon it. We do not propose to discuss what should be done in the immediate future, since this is complicated by so many considerations, such as the financial outlay which is justified by the existing volume of aerial traffic. But to simplify our question, let us imagine a time when the amount of aerial traffic will be so great that the financial considerations involved would justify any outlay that we are likely to propose. Such a time may be supposed to be many or few years ahead, according as one feels, pessimistic or optimistic, regarding the future of commercial aviation. Now one of the most useful results of the lectures given before this society is to afford a basis for discussion afterwards, and if we here put forward one scheme of action, it is hoped that the criticism and alternatives brought forward in the discussion will correct it where wrong and amplify it where needed.

It appears that meteorology should be of service in two main ways: (I.) by providing necessary information regarding all weather conditions which are likely to be encountered on any journey; (II.) by providing statistical information which may be required to settle certain definite questions and by explaining the physical causes of various phenomena.

Part I.—Daily Weather Service.

We may sub-divide this section into four parts, according to the information which is required by an aeroplane starting out on a long journey.

(1) Information regarding the probable wind which the aeroplane will encounter at any height at which it may fly along its route. This will be required both as an aid to navigation (almost essential if the flight be above clouds), and also for selecting the best height at which to fly.

(2) Information regarding the heights of the upper or lower limits of the various cloud layers, so that one may decide whether to fly above or below cloud.

(3) Ample warning must be given of any possibility of the clouds becoming so low as to touch the ground at any point along the route, or the formation of a ground fog.

(4) An indication of the general weather likely to be encountered along the route, with particular warning of any squalls, etc., which may be encountered.

To obtain an estimate of the probable winds, we may adopt one of two courses; either we may place our observing stations along the flying routes and telegraph to a central station (probably by wireless) the actual winds at certain fixed times, at fairly short intervals, or we can attempt to forecast the wind some hours ahead, in which case the observing stations must be located rather differently. The former is much the simpler method, and has the advantage that a few observing stations will suffice at first along the most frequented routes. As aviation progresses, and new routes become used, the observing stations can be extended along these also. Thus, no sudden demand is made on the exchequer, a point of considerable practical, if not scientific, importance! In this case we should make—at any rate at the beginning—little attempt to forecast the wind at a future time, but should trust to its remaining much the same as when the measurements were made. If this method be adopted the observations must be taken at frequent intervals and transmitted to the central station as quickly as possible. There seems to be a great advantage in employing wireless for the transmission of the information, for not only is there a saving of time, but also any large aerodromes can have their own wireless sets and pick up not only the information as sent out by the central station, but also such of the observing stations as are within its range can be picked up direct, without the delay of going through the central station.

The other alternative is to obtain as much information as possible about the wind and pressure distribution at various heights over a large area, and from this information to forecast the wind for any height, over any district, some hours ahead. A few stations scattered along the flying routes would be of no use at all for this purpose, as it would be essential to have a general view of the whole situation, and to find what changes were taking place, not necessarily at the flying routes, but in a large region round them. This method has the advantage, that the pilot is given a value of the wind for the actual time of his flight and not the wind which was observed a few hours previously. Against this must be set the fact that the process of forecasting will not give perfectly accurate results, even if supplied with the fullest information possible. I have attempted to find how large would be the improvement effected by forecasting, by comparing the errors obtained from trial forecasts which I made, with the actual change of wind in the interval of time for which the forecast was made. Unfortunately the improvement which I obtained was not nearly as large as might be expected, and would not justify any great outlay which might be necessary to obtain it. These results were obtained from forecasts of the surface pressure gradient and do not strictly apply to winds at, say, 5,000 feet or 10,000 feet; but at the same time the improvement effected by forecasting is not likely to be much better when we are dealing with the actual winds at a great height. It is true that the surface pressure gradient is almost certainly more irregular than that high up, but on the other hand we have many more observing stations on the surface than we should be likely to have for upper air work. The main disadvantage of this method, which admittedly gives rather more accurate results, is that to work it at all we must have a large number of observing stations from the start. Thus, the large financial outlay, and the difficulty of getting international co-operation—for observations would be required from a much wider region than the British Isles—would probably be prohibitive at first, considering the amount of aerial transport there is likely to be for many years.

We are thus led to conclude that it would be best to adopt the former scheme, at any rate, at first. As the amount of aerial traffic increased the observing

stations would gradually be extended along the various principal routes, and finally the addition of a few extra stations, in special situations, might allow the second scheme to evolve gradually out of the first. In coming to this conclusion we are, of course, looking at the matter from the point of view of a Chancellor of the Exchequer or the average taxpayer, and not from that of the meteorologist, who would gladly welcome any opportunity to obtain full and systematic information about the upper air.

We must now consider how our observing stations should be placed, and how and what observations should be made. The necessary observations seem to be:—

(1) Wind velocity and direction at all heights.
(2) Heights of the upper and lower limits of cloud layers.
(3) The temperature, pressure and humidity are also desirable.

The various possible methods of observation are:—

(*a*) Pilot balloons observed by theodolites from the ground.
(*b*) Anti-aircraft shell bursts.
(*c*) Sound ranging on pilot balloons with detonators.
(*d*) Determination of the wind from pressure gradients obtained from a number of simultaneous aeroplane ascents.
(*e*) Unmanned kite-balloons carrying recording instruments.

Of these (*a*) is ruled out, as it cannot obtain the wind, etc., above clouds; (*b*) is very expensive and can only be used in unfrequented places owing to the danger from falling fragments, it also requires co-operation of an aeroplane to obtain the wind above clouds, which again adds to the expense; (*c*) was used in France during the war, but there is some danger due to the possibility of the detonators not firing in the air and falling to the ground where they may be picked up by children; (*d*) has the disadvantage dealt with above, that a large number of stations taking simultaneous observations are necessarily required. On the whole (*e*) seems to be much the best. Instruments can be sent up on a fairly small unmanned balloon with certainty to 10,000 feet at all times, except in very strong winds. The running expenses should not be great, as with simple mechanical means of handling the balloon on the ground, very few men should be required. Once the balloon is in the air one man can do everything until it is necessary to take the balloon into its shed again. Observations can be made as easily at night as during the day, and could be made punctually to time.

Kite-balloons have already been tried for this purpose, and a few suitable recording instruments are in being. The instrument is fixed to the cable a few hundred feet below the balloon; as this has the triple advantage of allowing it to be easily fixed and detached—while the balloon is in the air—that it is well removed from any disturbance due to the balloon, and that it affords a much steadier fixing than if it is hung by a separate rope from the balloon. One record obtained by such an instrument is of interest since the balloon was above cloud nearly the whole time, and also since, owing to an accident, the cable broke at the winch when the balloon was at 10,000 feet, so that it drifted away to France with over 10,000 feet of cable hanging from it. It was recovered from there a year later and the record developed. The wind records above 10,000 feet were, of course, meaningless, but the temperature and heights were reliable. The height of the upper and lower limits of the cloud layers is obtained from the humidity record, but this part was not fitted in the instrument which made this record.

Instead of raising or lowering an instrument fixed to the balloon, one might have a number of instruments attached to the cable at various heights which should transmit their readings to the ground. While this is possible—schemes have actually been got out—the complication is great, and the objection to

lowering the balloon is very small. Another possible though awkward method would be to send the instrument by and down the cable by a small sail.

Assuming that we are to use a kite-balloon to obtain the observations, we have now to see how we should dispose the stations. Obviously, they must not be exactly on the route, owing to the danger from the balloon cable; they may, however, be placed, say 30 to 50 miles off the route, preferably on alternative sides. To settle how far apart the stations may be, and at what intervals of time the observations should be made, we require to know how the wind varies, both with change of place and change of time. This is some of the statistical information which we hope the kite-balloons will afford, and there is little accurate data at present. The amount of change will, of course, be different in different parts of the world. We have made a rough estimate of both quantities for the British Isles, both from the values of the pressure gradient, as shown on the daily weather charts, and also from pilot balloon results, etc. As one might expect, small changes of velocity and small changes of direction of the wind are the most frequent, and the frequency of a given change in a fixed interval of time becomes less, the greater the magnitude of the change. The results are somewhat different when we consider "vector" changes of velocity,* since a change in either direction *or* velocity will cause a change in the vector. In this we should expect changes of moderate magnitude to be the most frequent, both larger and smaller changes occurring less frequently. The curves which were obtained from the actual changes agreed fairly well with the theoretical results, assuming any change to be due to a number of causes. Further, it was found that as a rough approximation the magnitude of the average, or "probable," change in any interval of time, was roughly proportional to the square root of the time interval. A somewhat similar rule probably holds, for the average or "probable" difference in wind at any given time at two places at varying distances apart. As a very rough rule we may say that near the British Isles the "probable" vector† change of the upper wind in any interval of time is given by

$$V_t = 3.3\sqrt{t} \text{ m.p.h.}$$

where V_t is the vector change in t hours. A similar formula for the vector difference in wind at any time at two places at distance d miles apart would be

$$V_d = 0.5\sqrt{d} \text{ m.p.h.}$$

These formulæ are only suggested as simple very rough approximations to serve our present purpose and do not pretend to any accuracy.

Suppose we have observations made at the kite-balloon stations as frequently as possible, say every two or three hours, we must probably allow an hour for the collection and distribution of the results, so that altogether we may allow about three hours on the average, between the time the observations were made and the aeroplane flying on its journey. This by our formula would give a probable vector error of nearly 6 m.p.h. If we place the observing stations at intervals of say 150 or 200 miles along the route, the aeroplane should always be within about 100 miles of a station, and the "probable" error due to change of wind with change of locality would be about 5 m.p.h. in the worst case, when it was halfway between the stations. In view of the error due to change of wind

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* When dealing with aircraft navigation, we are generally not so much concerned with a change of velocity *or* direction of the wind alone, but with the result of the two together, or what is known as the "vector" change. For example, suppose the wind to be originally west 20 m.p.h. and then change to W.N.W., and to drop by $4\frac{1}{2}$ m.p.h. to $15\frac{1}{2}$ m.p.h., the vector change will be 8 m.p.h. to the S.W.; and an aeroplane flying in any direction for an hour after the change of wind and steering on an assumed wind of 20 m.p.h. W. will, at the end of the hour, find itself 8 miles to the S.W. of where it expected to be.

† Once out of ten occasions the "vector" change may be expected to exceed about 1.8 times the "probable" change, and in once out of 100 occasions about 2.7 times this amount.

with time, it does not seem necessary to place the observing stations at shorter intervals than, say, 150 or 200 miles.*

As regards the maximum height to which the observations should be made, a kite-balloon can fairly easily be sent up to 10,000 feet, but the expenses increase rapidly if greater heights have to be reached. As most commercial flying is likely to take place below this, 10,000 feet for the highest observation will probably be found sufficient.

With an organisation such as that sketched above, the navigator of an aeroplane ought always to know his wind, with a "probable" error of about 7 m.p.h., and the actual error would be less than 12 m.p.h. on nine out of every ten occasions. This accuracy is none too good, but it is, I am afraid, about as good as can be obtained. The scheme can be started on a few short routes without any great expense, and as well as being useful for immediate navigation purposes, could furnish statistical information of great value to aeronautics.

The second requirement, viz., the heights of the cloud layers, can be obtained from the kite-balloon instrument by means of a recording hygrograph. In addition, it has been suggested that the instrument should take photographs at certain heights to show the types of the clouds.

We now come to the third requisite of warning in any cases where it is possible that the clouds may come so low as to touch the ground at any part of the route. Without this it is doubtful whether there will ever be much over-cloud flying, owing to fear of having to land in the cloud. Forecasts of ground fog are also desirable. Little seems to have been attempted up to the present in the way of forecasting low clouds, from which we can judge the chances of success. However, examination of the humidity of the oncoming air, and the vertical temperature gradients, together with experience of the cloud heights under similar conditions in the past, would probably allow fairly reliable warning to be given of the possibility of the clouds coming down to the ground. Mr. G. I. Taylor has already put forward a scheme for giving warning of the formation of ground fogs in the early mornings, but I do not know of any cases where it has been systematically used.

Finally, the forecasting of the ground weather conditions is much the same problem as is tackled every day in the daily weather report. Special squall warnings would probably be useful. Such a service for squall warnings was in operation in Germany before the war. A very large number of small post offices scattered all over the country, were instructed to telegraph to a central office whenever a squall occurred. By plotting the positions and times of the squall on a large map, it was possible to see how it was moving, and send warning to those places towards which it was travelling.

We have now completed our review of what we consider the best daily meteorological service that is possible for the benefit of aviation, but before closing, the reader will probably not rest satisfied with an indication of how ground fogs may be forecasted, but will wish for some reference to the possibility of clearing small areas artificially when aircraft wish to land. The various proposals for doing this seem to have been attracting considerable attention lately.

There is no fundamental theoretical reason why it should not be possible to clear fog artificially over limited areas. Indeed, if the air were only still, the fog droplets would fall to the ground by their own weight at a rate of something like a metre per minute, so that they could clear themselves in a comparatively few minutes. Again, no appreciable energy would be required to make say 1,000 droplets slowly collect together, when they would form a drop big enough to fall

* Where the causes of error are not connected in any way, the error due to many causes together is obtained by finding the square root of the sum of the squares of each error, and not by simple addition.

in spite of the turbulence always present, and which prevents the smaller drops reaching the ground. In actual practice, however, the problem does not seem very hopeful. The air is never still, but has always a slow drift of a few miles per hour, and the direction of this drift is often far from constant. Let us now examine some of the suggested schemes, and let us take as an example that we wish to clear a patch large enough for an aeroplane to land on. If we could maintain it perfectly clear, an area 30 yards wide, and say 300 yards long would suffice, but owing to the variable direction of the drift of the air we ought probably to clear a lane quite 100 yards wide and probably more. Let us suppose that the fog is 300 feet deep (and it is often much more), that the wind is 2 m.p.h. (which is probably a low estimate), and that we are to clear all the air which comes over a line 100 yards long at right angles to the direction of the drift. All these values may easily have to be increased considerably.

(1) Artificial Warming.

One suggestion is to warm the air by burning coal, say by having a number of small portable furnaces, which could be arranged in a row. Now to evaporate all the water which exists as drops and warm the air, say 3° C.—so that the fog would not quickly form again as the air cooled—would require about three tons of coal to be burnt per hour, assuming all the heat used to the greatest advantage. Allowing for inefficiencies, probably at least ten times this amount would be required. Such an amount would not be out of the question, but it would need considerable apparatus. The nuclei produced by the burning coal would tend to form a fog themselves, so that the warming would be to some extent counteracted by their presence, but to what extent it is difficult to say. Were it not for the fact that during a fog the usual temperature gradient is generally reversed and the air gets warmer upwards, the heated air would simply rise and draw in more foggy air behind it. This might actually occur on some occasions, when it would be impossible to clear the fog by warming.

(2) Artificial Drying.

If we were to blow into the air a substance like powdered calcium chloride (which is fairly cheap) the water of the drops near any grain of calcium chloride would evaporate and condense on the grain, which would grow in this way until it fell out by its weight. In this case also we should theoretically need about three tons of calcium chloride per hour, but it might be possible to use it with better efficiency than coal, and of course it could only be used for the few minutes just when required, whereas in the scheme for warming the air the fires would always have to be lit in readiness. Once the air was cleared in this way it would remain clear much longer than if it had been warmed.

(3) Electric Discharge.

If a pointed rod be introduced into a jar containing artificial fog or smoke, and be charged electrically till a brush discharge takes place from the point, the fog is quickly cleared in a remarkable manner. Methods of this type have frequently been suggested, but it seems certain that all the imaginable effects of an electric discharge (which easily account for the clearing in a jar) would be enormously too small to cause any appreciable clearing on a large scale. I have not been able to find any positive results where experiments have been made in the open with this method.

If the fog droplets were electrically charged they could be caught on a conductor carrying an opposite charge, or by spraying the air with larger drops of water also charged. Actually, however, the fog droplets—as one would expect—are uncharged except for the minute charge, either positive or negative, which most small particles possess, amounting to not more than that of a few electrons. Such a charge would be quite useless for any method of clearing fogs.

Another suggested electrical method is to charge all the fog droplets artificially—say positively—and then arrange a negatively charged body to catch the charged droplets. We must remember, however, that a fog droplet having a radius of the order of a hundredth of a millimetre cannot retain its charge if the potential be above about 30 volts, which would correspond to a charge of something like 10^{-4} E.S.U. Effects due to such a charge would be negligible. If charged to a higher potential, the air near the droplet is ionised and the charge leaks away.

We may also point out here, that since in an ordinary fog the droplets of water amount to something like 1/5 c.c. per cubic metre of air, if all the droplets were removed in the case considered above, they would form a stream of some 20 to 30 gallons per minute, *i.e.*, it would require a 3 or 4 inch pipe to carry it. Thus, even if we try to clear such a small area as that taken above we have to deal with a considerable quantity of water.

Part II.—Statistical Information.

As regards the second part of our subject, viz., providing sundry statistical information for the use of aviation, there is comparatively little to say. This problem is very much easier than the first, though, of course, somewhat dull except to those who immediately require the information. We have seen, for example, that we ought to know roughly the "probable" change of wind in any interval of time, and between two places any distance apart, for various parts of the earth's surface; also such information as the change of wind with height. In addition, of course, it is important to know the prevailing winds at any place where the winds are sufficiently regular to make the information valuable. Much of this information, especially that applying to the atmosphere near the ground, is already available, and the remainder can nearly always be obtained if it be considered of sufficient importance to spend the necessary amount of money in obtaining it—as, for example, by equipping the necessary kite-balloon stations.

When dealing with statistical information such as the prevailing winds at any place, one must remember that it is of comparatively little value to find the average or most frequent wind, unless we also know how often the wind departs from this value by any given amount. Thus, if we took the British Isles we should find the prevailing surface wind to be approximately S.W. and I suppose about 15 m.p.h.; this information, however, would be quite useless for aviation, as the chances that any given day has a wind very different from this are very large indeed. As another example we may take the distribution of pressure, temperature and density of the air, with height. This will show us, for example, how we should calibrate an aneroid to obtain the most accurate readings, but we require the standard deviations of these values to calculate how often errors of any magnitude will occur.

As we mentioned above, the obtaining of statistical information is usually chiefly the expenditure of the requisite amount of money, and statistics being proverbially dry, it is not proposed to discuss the subject in detail.

In conclusion I fear the average aviator whose patience has carried him this far, will doubtless feel some disappointment that the meteorologist is not likely to help him more in his daily work. I wish it were otherwise, but the values that are given above are those which are the nearest the truth so far as I can arrive at it. At the same time a meteorological service such as we have imagined would be no small advantage to commercial aviation, and if the best value of the wind which can be given to a pilot starting on a flight has a probable error of 7 m.p.h., it is probably sufficiently good to allow him to navigate by it, say above cloud, without reference to the ground, or on coming down through the cloud to pick up his position relative to the aerodrome without trouble.

DISCUSSION.

The CHAIRMAN said he thought it would be better to take the discussion on Major Dobson's Paper straight away. They had now had an unofficial view of the needs of aviation as regarded meteorology. It would be best now to hear something from the other side. He would ask Colonel Gold to open the discussion because he organised the war meteorological service in France, and is in charge of the meteorological service for aviation in this country. He had practical experience, and would set the discussion going.

Colonel GOLD said the Paper was an effort to stimulate meteorologists to greater precision. On reading the Paper through one got the impression that the author was rather more pessimistic about the usefulness of meteorology to aviation than he (Colonel Gold) thought an all-round survey of the subject entitled one to be. The Lecturer had rather confined himself to the idea of flying over clouds or in cloudy weather, and, in that connection, to the accuracy with which information as to the wind could be obtained by the meteorologists. But even if all Major Dobson said were the limit of the meteorologists' powers in dealing with that particular problem, he (Colonel Gold) did not think it would represent the limits of usefulness of the meteorologists to the aviator. He quoted an example which occurred on November 4, 1918, in France. It was a beautiful evening, but he saw from the weather charts that there was going to be a rapid increase in the wind velocity and deterioration in the weather. A forecast to that effect was issued, and it was evidently of service to the aviator, because the next day they received a telegram in the following terms:—"Warmest thanks from 54th Wing for your invaluable forecast last night." If the aviators had had merely exact information of the weather at the place they were going to they would probably have lost their machines; because at both places the night was cloudless without much wind, and things appeared about as favourable for flying as they could have been. That illustrated the main point—that observations along the route could not, *in themselves*, be adequate. They must be combined with meteorological information of the conditions over the area and forecasts of changes along the route. It was necessary to make some distinction between long and short flights. One of his earliest recollections that convinced him of the importance of meteorology for aviation was the case of a pilot starting from Hendon to fly to Scotland. The conditions appeared favourable, but he struck bad weather, which, to a meteorologist, it was obvious that he would strike, as it was coming in rapidly from the west. He crashed in Yorkshire and was killed. If he had been going on a short flight, say, from London to Lincoln, the conditions would have continued favourable long enough for his flight, but on the long flight the conditions had time to change to such an extent as to make the completion of the flight impossible. For a route such as that from London to Manchester he agreed that the best way to secure efficiency would be to have observations such as Major Dobson suggested by means of kite balloons at different places along the route, *combined with general synoptic information,* so that one knew the existing conditions and the changes likely to take place. It was when such changes were likely to take place and their coming was obvious to the expert meteorologist that accidents occurred. More than half the accidents due to the weather arose, not through conditions being bad at the time, but through their becoming bad and through the forecast side of the subject being neglected. A pilot was not so much concerned with the weather at the time he began his flight as with the weather later in the flight and at the time he had to make his landing, and for that a forecast was essential. Although the actual weather in 80 per cent. of the day time occasions might be a good forecast of the weather two or three hours later, it was not always so. What made aviation difficult were the occasions when the actual weather was not an indication of the weather two or three hours later. The Lecturer suggested that they must have one of

two things, either kite balloons along routes or observations of upper air temperatures and pressures taken at different places over the area. He himself did not regard those as alternatives but each as supplementary to the other. He thought the practical development of the idea of getting observations of temperature and pressure over an area in such a way as to enable charts to be made at the different levels in the atmosphere arose out of the proposal to bomb Berlin. The late Colonel Hopkinson, after discussing the matter with him in France, came to England and began the organisation of a series of stations from which such observations would be available. Such stations were essential if the conditions over such distances as that from England to Berlin were to be forecasted; moreover in everyday work the direction in which real progress was looked for in meteorology was by utilising, from a number of stations, observations of the upper air pressure and temperature; the number of those stations need not be anything like so large as the number of surface stations, because the surface distribution and one's knowledge of its normal relation to the conditions in the upper air permitted of a first approximation to the upper air distribution. Four or five over the British Isles would be adequate, whereas for surface charts at least 20 stations would be required. With a dozen stations over Western Europe all giving observations of pressure and temperature at different heights they would be in a different position from their present one in regard to making real improvement in the deductions which were translated into forecasts. That would be a more fundamental improvement than an improvement obtained by getting observations further to the west, because it would result from a better understanding of the processes involved. He ought to have described the arrangements which were already made for meeting the needs of aviation from the meteorological point of view. Briefly there were two types of information supplied, the general synoptic type and the local type. For the former one had information from 20 stations in the British Isles, 15 or 20 in France, and others in Denmark, Norway and so on, and a weather chart was made from which one could say, sometimes with great accuracy and sometimes with less accuracy, the changes that would take place in the next 24 hours. Those reports were made every six hours, so that one could make progressive deductions correcting or confirming one chart by the next. Supplementing these, especially over the London-Continental routes, there were a number of stations reporting, not so much instrumental observations like barometer and temperature, as observations of more direct importance to aviation—the clouds, the height of the clouds and the visibility and the weather in the ordinary terms. So it would be seen that, as far as surface observations and upper air observations in reasonable weather were concerned, they had got what Major Dobson advocated. What they lacked was the upper air observations in bad weather to be obtained from kite balloons along the route London to Paris. These were difficult to get, and could only be obtained by common action on the part of England and France.

The question of fog was considered a good deal in France during the war, and they used regularly conclusions somewhat as follows:—During the period from April to September: (*a*) if the wind at 9 p.m. was above 8 miles an hour there was little risk of fog or mist; (*b*) if the wind was dead-calm there was considerable risk of fog or mist, whatever the thermometers (dry and wet bulb) might read; (*c*) for winds between those the risk of fog or mist depended on the difference between the dry and wet bulb thermometers. They had a table which, in conjuction with other features on the chart, indicated whether fog or mist would develop during the evening.

Statistics were of real importance in any organisation. One would like to know whether a place chosen for an aerodrome was particularly liable to local mists or whether the cloud was half the year within 200 or 300ft. of the ground (as at Princetown), or whether the rainfall was 30ins. or 90ins. and so on. From past statistics one had information about the rainfall and the wind, but no

precise information about the prevalence of low cloud, the height of low clouds and the visibility in the exact terms in which it was obtained to-day. Statistics were also required, in the location of aerodromes, as to the direction from which gales came. In one part of the world nearly all the gales came from the south-west, in another from the north or north-east. In the early days in France, aerodromes were constructed, he believed, so that the hangars opened towards the north, whereas the direction in which they got fewest gales was east-south-east. Occasionally in that part of France they got sudden and severe gales from the north, so east-south-east would have been a more favourable aspect than north. They had, however, realised what the Lecturer had pointed out, and would take his Paper as something to stimulate them to make greater efforts in securing precision, not merely in their observations, but also in interpreting them and forecasting for short periods.

Major-General Sir W. S. Brancker said he had often remarked before that meteorology was the very life-blood of commercial aviation. Flying in really bad weather was the one problem of which he could not quite see the solution. It was of vital importance to have rapid weather reporting of local conditions in front of a machine which was trying to fly somewhere. He agreed with the Lecturer that the rapid reporting of local conditions and its rapid translation to the points of departure and arrival was better than the forecast system. The latter was useful to let one know generally what was going to happen, but it was of the greatest importance, just before any particular service was timed to start, to get instantaneous news of the weather in front at the various stages. He did not think there were many accidents caused by the weather. What he was thinking about was regularity in flying, which was interfered with by bad weather. In commercial aviation one must offer regularity both by day and by night, and air services could be made perfectly regular to-morrow except for that one factor of the weather. The Lecturer suggested that the balloons should be 150 to 200 miles apart. That was rather far in this sort of climate. Taking London to Paris, weather reporting stations would be wanted on each side of the Channel and at each end of the route—four stations for 220 miles. If the balloons were 30 or 40 miles off the route they could give only secondary information. Information was wanted direct from the route. It was found in connection with the Paris service that reports from Beachy Head and North Foreland were not of much use. The Lympne and Boulogne reports were most valuable. He had heard it suggested lately that a government official should be appointed *to commercial aerodromes,* who would not only be responsible that all machines were fit to fly, but would also decide whether the weather was fit for flying. He was absolutely against having government inspectors to see that machines were fit and to judge as to whether the weather was fit for flying. The man to decide that was the man in charge of the service at the aerodrome; when aircraft grew bigger it would be the captain of the ship.

Colonel Beatty agreed that what a pilot wanted was information as to the actual weather rather than a forecast. For commercial work he wanted to know first, was it possible to land at his destination? Secondly, would there be any change in the weather there during the next two or three hours? After that, and subsidiary to it, what weather conditions was he likely to encounter en route?

Information as to the upper wind was not of much value to pilots at present, as commercial flying was mostly done at a low altitude and the pilot could determine the strength of the wind there from his own observations in any reasonable weather.

Major Dobson had specified various instruments as required for the purposes of observation, but had not mentioned the observer. He would probably agree that it was most important to have at the terminal points a really good observer

upon whom the pilots could thoroughly rely. The man was more important than the instruments.

He entirely agreed with Sir Sefton Brancker in his objection to the proposal that government inspectors should decide whether the weather was fit for flying.

Major H. G. Brackley thought what pilots wanted was an accurate report before they started on a flight. At present a number of pilots had not the fullest confidence in the reports or forecasts they had, and would sooner rely on their own judgment than on a report that the weather was all right at the other end. As regarded over-cloud flying, most pilots would rather keep in sight of the ground. He had done a fair amount of above-cloud flying, but not without a lot of fear as to when he would see ground again, and in a number of cases he did not see it for about two hours. For commercial flying it would be best to keep in sight of the ground as much as possible, though if the country were hilly and the clouds low it would be more difficult to decide whether to keep above the clouds for a time. The pilot could only do it if he had a wireless telephone to tell him the weather was all right farther ahead. Captain Timms had asked him to suggest that after the development of aviation and greater precision in navigation, additional sources of information would be available. Pilots or navigators could send reports on routes by wireless telephone of the heights of clouds and the wind velocity at the height at which they were flying, and the multiplication of those reports would assist meteorologists in compiling statistics as well as other pilots crossing the same area. To make the system complete it would be necessary to make the reporting and recording of observations compulsory. He agreed with that too. They could be of great help to those who followed them on the route.

COMMUNICATED.

73, Melrose Avenue,
Cricklewood, N.W.2.
February 10, 1921.

Dear Sir,—With reference to the Paper on "Meteorology and Aviation" by Major G. Dobson, which was read at a meeting of the Royal Aeronautical Society last Thursday, February 3rd, I was unable at the lecture to make a remark on the subject of meteorology and am therefore putting it on paper.

The Air Ministry recently issued in the form of a "Notice to Airmen," a list of specimen questions on navigation, covering the syllabus of the examination which is to be enforced for all applicants for civil aviation pilots' licences in the future. There are 136 questions given, but not one is on the subject of meteorology!

It has been stated not once but a hundred times that meteorology is of primary importance to aviation, and so the total absence of questions on the subject from the Air Ministry syllabus is greatly to be deplored, but I feel sure that the omission is an oversight.

Meteorology is so bound up with aerial navigation that it is part of it, and the future pilot who will have to cover long distances over the continents of Africa, Asia and Australia, not counting the American Continent, will have to depend more on his own judgment of the weather than on reports received from meteorological stations, because for a long time yet these continents will be very poorly served—compared with Great Britain—by meteorological services.—Yours faithfully,

H. R. Gillman.

NOTE ON MAJOR DOBSON'S PAPER ON METEOROLOGY.

This Paper appears to deal with meteorology for only comparatively short flights of a few hundred miles. It is suggested that meteorologists should turn their attention to longer flights, and it would be of considerable interest to know what they could do with the present means at their disposal in the forecasting of weather for flights say from England to Egypt, thence to India, China and Australia. Of course, such detailed information could not be given as in the case of a short flight. The main points that are required would be the movements of depressions while the flight is taking pace. It would be of very great value to the pilot if he could obtain reliable information by wireless as to the approach of depressions, their probable direction and rate of progress.

Another point which requires investigation is the examination of the upper atmosphere over disturbances causing high surface winds. During R.34's flight to America comparatively fine weather was found above the clouds where there was a very heavy sea and wind on the surface.

With reference to Colonel Gold's remarks on forecasting the weather, it is noted that he smiled almost audibly at the suggestion that people, other than meteorologists, could guess the weather. It should be pointed out that meteorology in its modern meaning is a very young profession and should, therefore, be proportionately modest in its attitude towards other people who are endeavouring to foretell the weather. There is, however, a profession of some considerable age which has dealt with wind and weather for many centuries. It is interesting to note that modern meteorologists are re-discovering facts which were known to the sailor for a long time. For instance in a Paper read before the Society on meteorology by H. D. Grant he mentions that an approaching depression may be foretold by the sight of low-lying cumulus clouds in the distance, and he adds that they are frequently difficult to see owing to the haziness. They are easily detected, however, at sunset as the sun disappears when it is three or four degrees above the horizon. This has led to the old saying :—

"If the sun sets behind a bank,
A westerly wind you will not thank."

I have heard of no parallel to the remainder of this couplet, which states :—

"If the sun sets as clear as a bell,
An easterly wind as sure as hell."

Another instance of this is seen in Colonel Gold's story of foretelling bad weather on a day that appeared to be fine and clear. The old saying that corresponds to this is : "That the worst gale that ever blew came out of a clear sky." There are many other signs too long to catalogue here. I will only mention the firm belief in the influence of the moon on weather.

These sayings are not wild guesses of ignorant men ; they are the result of centuries of experience and should not be lightly ignored, and I think useful purpose would be served by studying them and seeing if scientific explanation could be found for them.

I have instanced one or two cases in which meteorologists have agreed with them, and it is possible that many others will be found to be true as well. Meteorological forecasts in this country are usually given in a very general form, such as "fog in places." This does not help one much, as you still have to guess where these places are, and I think with such a variable climate as we experience in this country considerable use can be made of the ability of guessing, if this be combined with the science of meteorologists.

WOODIS ROGERS.

The CHAIRMAN congratulated Major Dobson on the assumption with which he commenced his Paper—that there were unlimited funds. It was advisable to start with such an assumption, and see what was the ideal to strive for and use the funds available to the best of one's ability to get as near the ideal as possible. Sir Sefton Brancker hit on the fundamental thing, did one want the conditions at the moment along the line or a forecast? It was all very well to say a pilot would rather judge for himself what the conditions were at the other end, but if he could get information from the meteorologist at the aerodrome that there was a fog at the other end he would like to know about it. If, however, one only wanted to know the conditions along the line one had only to tell the meteorologists that was all that was wanted, and they would make arrangements accordingly. But they could not have the above-cloud conditions in that case. It took too great a "bandabast" (to use an Indian expression) to get the above-cloud wind velocities. They could give pilots the height of the clouds and whether they were increasing or decreasing or getting higher or lower. When it became necessary to tell a navigator how to set his instruments or reach a certain point something must be done in the nature of Major Dobson's suggestions. There were considerable objections to kite balloons. They were very expensive and dangerous. After they had been in service for some time air leaked into the envelope and an explosive mixture was formed. They had to be carefully housed, and all sorts of regulations had to be enforced, and it took a long time to get the balloon up to 10,000ft. and to pull it down, develop a record and get results from it. An aviator might get a certain distance off his route, and he would not feel happy if he knew kite-balloons were about. Major Dobson reported how one of his balloons broke away at the winch and 10,000ft. of wire went trailing through the air to France. Meteorologists could get most of the information they wanted from flights by aeroplanes which would take the temperature when ascending and descending. The temperatures could be reduced to heights, and they would have the crude material for calculations. They could calculate from the temperatures and the synoptic charts of the ground observers what the wind would be at different heights, its velocity and how it changed. These aeroplane observations would be wanted four times a day. He looked forward to the day when pilots themselves would be meteorologists. He was disappointed when he went to Croydon to see the use made of their charts by aviators. He came to the conclusion that if the pilot could get his machine off the ground he would go where he was sent, and therefore he was not so interested as the manager of the aviation company, who he understood did study the charts. He looked forward to the day when the pilot would know the ordinary meaning of the isobaric chart. If a pilot looked at the map and saw there was a small depression at a certain place which would give him bad weather he would remember that better than statistics as regarded conditions along the route. As an official meteorologist he would like pilots to come to his office and discuss their difficulties or say how they would like things. By such co-operation they would reach the end they all desired. He was not sure they had not practically got the unlimited money Major Dobson assumed. Since he had taken over the Meteorological Office he had never had his activities really stopped by want of money, and as long as General Sykes was the Controller-General of Civil Aviation he felt sure he would be sympathetic towards every aspect of their work which was economically good in the broad sense.

Mr. DOBSON, in reply, writes:—Colonel Gold's criticism is very interesting and instructive, though I do not think there is really so much difference between his views and those expressed in the Paper as might at first sight appear. There is no doubt whatever that all the surface information which is available should be used to the fullest extent, to obtain an estimate of probable changes in wind and weather. The suggestion is rather that this should be added to the reports of the existing upper air conditions, etc., along the route. In the brief abstract of the Paper given at the meeting, I am afraid I may have given the impression

that the two alternatives were, either forecasting by surface conditions, or use of direct upper air observations *only*. The alternatives I meant to imply were rather the placing of the available kite balloon stations in positions suitable for drawing synoptic charts for high levels, or for obtaining the actual upper air conditions along flying routes; and the contention was that—at any rate at the start—the latter method would be the better.

As regards statistical information, its importance is emphasised in the Paper, but it was thought that the subject did not lend itself to general discussion. Colonel Beaty has suggested that observations above cloud are not really required, since commercial aircraft always fly below cloud. Is it not, however, the case, that they fly below cloud (1) because they have no information of the wind above, by which to navigate; and (2) because they have no certain information that the cloud will not come down and touch the ground at the destination, or at some point along the route; and further, is not this a very serious handicap to flying, which could be removed by an ideal daily weather service.

Dr. Simpson objects to kite balloons, (1) because of the time required to take and reduce the observations; and (2) because of the danger of the wire, and advocates aeroplane observations of pressure and temperature instead. As regards (1) it takes about thirty minutes to haul the balloon down from 10,000ft., and about ten minutes to develop and reduce the record, so that the earliest observation is only forty minutes old. The taking of pressure and temperature observations by aeroplanes, and their comparison with those taken at other stations, in order to obtain the pressure gradient, and from it the wind, at any height, will certainly take longer than this. (2) The wires of the kite balloons would, of course, be well flagged, but the real safety would be obtained by having them some distance off the routes.

He has not, moreover, overcome the two great difficulties which are inherent in the aeroplane method. As pointed out in the Paper, to obtain pressure gradients at heights from which we can obtain reliable wind estimates, would require a considerable number of simultaneous and well distributed observations. This necessarily involves initial expense. The experience with aircraft is almost unanimous in bringing out the great difficulty of obtaining regular observations in almost all weathers. The experience at Orfordness during the war, when questions of safety hardly came in, and with the keenest of pilots, showed that one could not get anything like regular results. After working amongst aeroplanes for over seven years, I am personally quite convinced that such a method cannot provide the regular and accurate observations made to time which are required.

A still further objection is that, even when sufficient observations are available to allow a pressure map to be made for upper levels, we are still some way from obtaining a reliable estimate of the wind.

Several criticisms have been made on the fact that the scheme only appears useful for short flights. This is quite definitely the case, though I would put the distance at say 500 miles rather than 100 as some speakers suggest. Except for airships, aircraft will certainly have to land about once every 500 miles, and then can get information for the next stage even if they have not got wireless communication all the time. With regard to forecasts of journeys of several thousand miles, it will obviously be impossible to give the wind for the whole journey at the start, and this must be obtained at the beginning of each stage. The general weather conditions would be obtained from surface observations just as at present, and a useful forecast might perhaps be made two or three days in advance.

Lieut.-Col. H. W. S. Outram then delivered his lecture as follows:—

GROUND ENGINEERING.

PART I.

Introduction.

(1) The development of aircraft during the war was such that a new and reliable means of transport had come into existence before the Armistice was signed. It possessed the supreme advantage of greater speed than any other form of public transport, although the commercial possibilities of the new service had still to be proved.

A committee was formed under the chairmanship of Sir Frederick Sykes, and as a result of a series of meetings held during March and April, 1919, framed the first Air Navigation Regulations and the directions issued thereunder, which became a part of the law of the land on April 30th, 1919.

In this paper I propose to deal with the sections of the regulations and directions concerning ground engineers.

Schedule 3, paragraphs 5, 7 and 8 of the "Regulations" read as follows:—

(5) All passenger aircraft must be inspected, overhauled and certified as airworthy by competent persons appointed by the owners or users of them, and licensed for the purpose under this schedule, at such times as the Secretary of State may direct, and such certificate or certificates must be produced to the Secretary of State on demand.

(7) No passenger aircraft carrying passengers shall on any day proceed on any journey unless it has previously been inspected at least once on that day by a competent person licensed for the purpose under this schedule, who shall not be the pilot of the particular machine.

(8) If such competent person is satisfied that the aircraft is fit in every way for the flight or flights proposed, he shall sign in duplicate a certificate to that effect, which certificate shall be countersigned by another person in the employment of the owner, giving the time and date of such certification. For this purpose the counter-signature of the pilot may be accepted."

Section IV. of the "Directions" refers to the "competent person" as a ground engineer, and details the procedure for licensing and the form of certificate they are required to render when carrying out their duties.

(2) Three years ago the title of "ground engineer" was unknown. To-day the term is familiar to very few of the general public, and its exact signification to a still smaller number. It is hoped that this paper may clear away any misunderstanding regarding this new profession; provide fuller information than is at present available for candidates desiring a licence as ground engineers; and that the discussion will assist towards our main object, the maintenance of an ever rising standard of safety in aeronautical travel.

(3) It may be well to consider at this stage why the creation of a new class of official was necessary. Every form of public transport is under some measure of Government control. The railways, although their vehicles operate only on their own property, have to conform to Board of Trade Regulations. Public transport services using the seas, the highways, and the rivers are under a larger measure of control in that not only are the members of the public who travel thereon safeguarded, but also the safety and convenience of other users.

The case of aircraft, while similar in many respects, differs fundamentally in that any other form of public service vehicle on land or sea once built in accordance with prescribed conditions and operated under certain limiting regulations only loses its measure of safety through accident, or by a slow process of

deterioration which can easily be detected by its behaviour and checked by occasional external examination. It is possible by the examination of the design of any aircraft to forecast its behaviour in the air, and comparatively easy by careful and detailed inspection to ensure that it is built in accordance with such design and of the required materials. As a result we can certify that the completed aircraft is airworthy, and guarantee that no undue risk will be taken by its passengers or caused to that section of the community over which it passes in its various flights. At the first landing some small damage may be done to some important part of the structure; during the first flight some part of the controls may wear, or a single but vital nut loosen, and in consequence, the aircraft, although landing safely, without any outward indication of the trouble, may within a few hours of the issue of the certificate of airworthiness have passed into a dangerous condition. In other words, a certificate of airworthiness is valid only until the aircraft takes the air, and its validity must be maintained by repeated examination, to prove that everything is in the same condition as when the certificate was first granted.

The ground engineer has been appointed to carry out these examinations.

PART II.

Examination of Ground Engineers.

(1) A candidate, having applied for a licence as a ground engineer, is requested to attend an examining board composed of Air Ministry inspectors. The result of this examination guides the Controller General of Civil Aviation in his decision as to whether the candidate is qualified for a licence.

It has been suggested that the examination should be in part or wholly written, but the experience gained in the last two years is rather against such a procedure, and in favour of retaining the *viva voce* method. When the various courses in aeronautical engineering that have now been introduced at certain colleges are in operation, their successful completion may possibly be accepted as replacing a part of the present examination.

(2) It cannot be too strongly emphasised that any such examination only guarantees to weed out those who are insufficiently qualified. Alone, it cannot prove that all those that "pass" are fully qualified to discharge their important duties. An examining board, having considered a candidate's past experience, questioned him, and formed their joint opinion on his abilities, can do no more than state that in their opinion he is reasonably likely to be an efficient ground engineer. We have had examples of men who have shown brilliance at such examinations, but have developed in practice some little failure in personality which has prevented them carrying their extensive knowledge into effect. It would appear, therefore, that the only way to determine definitely whether a man is a properly qualified ground engineer is to watch him at his work, and in particular to note the results of such work.

The figures given in Appendix I. show that some preliminary elimination of the unqualified candidate by examination is essential. Since the publication of the Air Navigation Regulations in April, 1919, and up till 1st January, 1921, 664 candidates have been examined; 509 passed and and 155 failed. Of the 509 who passed many had applied for a full licence, but were finally recommended as qualified only for a licence in one category, and even that endorsed to apply to but one or two types, as explained hereunder.

(2) It is seldom that any one man is called upon to cover the whole range of a ground engineer's duties, which would call for knowledge of the construction of aircraft, construction of aero engines, and the operation of both the engine and the aircraft.

It has therefore been arranged to issue licences for a part of these duties, to enable men to carry out that section for which they are suitably qualified.

Ground engineers' licences are divided into four main categories:—

(*a*) Rigging and daily maintenance of aircraft at the aerodrome.
(*b*) Overhaul and construction of aircraft.
(*c*) Top overhaul and daily maintenance of the engine.
(*d*) Overhaul and construction of aero engines.

It was found that many candidates required licences for duties for which they were qualified, but which formed only a part of any one of these categories. For example, several candidates only required a licence to certify the overhaul of one particular type of aero engine of which they had the requisite knowledge and sufficient experience of the construction, though they knew little or nothing about other types. In such cases, therefore, it was arranged to recommend the issue of a still more limited type of licence in one category only, endorsed as being restricted to the particular type of engine or aircraft of which the candidate possessed the requisite knowledge.

(3) The examining board report on each candidate's qualifications, and from these reports one fact is most apparent. The majority of candidates may be divided into two classes. One class has a sound knowledge of aerodrome practice, a fair knowledge of ordinary workshop methods, and a surprising ignorance of the qualities of the materials from which an aircraft or aero engine is built, and even less of the many ways in which such materials may be spoilt by bad treatment and ignorance of their peculiar properties. The other class consists of men whose experience has been limited to a large extent to the construction of aircraft or aero engines, and who have gained the knowledge of materials referred to above, are expert in modern aeronautical workshop practice, but have only a very general or theoretical idea of what happens when the aircraft takes the air. Each of these classes is again sub-divided into the metal-worker and the wood-worker. Generally a candidate with good and sound knowledge of metal work has but an elementary knowledge of wood and non-metallic materials, or his knowledge of the latter predominates. Only a few men have shown equally sound knowledge of both branches of aircraft construction.

It has been found that in the majority of cases a candidate can be placed in one of these classes within the first few minutes. The remainder of his examination is spent in ascertaining whether his experience and knowledge in the other divisions are sufficient to warrant a recommendation.

It has also been found that the examination of a successful candidate seldom lasted more than half an hour, but on the other hand it is often necessary to prolong the examination when candidates have failed to convince the examining board of their ability.

On occasion the employers of candidates who have failed have challenged the decision, stating that the man failed was in their opinion a better man than another of their employees who had passed. In such cases inquiries have usually shown that the man may have been a better workman, but was insufficiently qualified to inspect the work of others.

The ground engineer is in many cases engaged in the first instance as a mechanic, and from his employer's point of view his qualifications as a ground engineer may be subsidiary thereto. Only his qualification as a ground engineer can be considered when deciding whether he is entitled to a licence.

PART III.

The Supervision of Ground Engineers.

(1) As has already been mentioned in Part II., the examination of a ground engineer is only completed when his work has been watched.

This is one reason why he must be supervised, but the greatest need for supervision is that the knowledge that this exists, and is effective, provides that

power behind him necessary to enable him to enforce his decisions. The best ground engineer may be faced with the alternative of issuing a certificate for a doubtful machine or the risk of dismissal and replacement by a less conscientious man. If ever, therefore, an operator suggests that his ground engineer should grant a certificate against his inclination, the latter should be able to reply that he cannot do so, since the supervising inspector would recommend the cancellation of his licence, and any certificate would thus become invalid.

On the other hand, the simplest way for a ground engineer to carry his responsibilities is to insist upon immediate replacement of each and every part so soon as the first sign of wear became apparent. Commercial considerations, however, inevitably tend to postpone that moment, and an opposing force is required, obtained by supervision by a disinterested party.

(2) In order, therefore, to supervise the work of the ground engineer, the power of reinspection provided in paragraph 6 of Schedule 3 of the Regulations and paragraph 8 of Part IV. of the "Directions" is exercised.

It was found at an early date that it was impossible to keep in touch with each individual holder of a ground engineer's licence, since a large proportion of those who successfully obtained such licences did not operate.

It was therefore decided to arrange for periodical reinspection of all aircraft in use, and thereby supervise the work of the active ground engineers. The method adopted is as follows:—

All certified aircraft must fly from licensed aerodromes. The Air Ministry have a complete list of such aerodromes, which is kept up to date. Each is visited in turn, and the aircraft examined, the work done by the ground engineers responsible for the daily certificates for such aircraft being checked and noted. The reports thus obtained on each ground engineer are sub-divided and recorded.

It has been found that this method gives a useful record of nearly every ground engineer who is operating. Should any escape such supervision, the fact becomes apparent when they apply for renewal of their licence, and in such cases particulars of the work done are required, special arrangements being made to judge therefrom as to the man's capabilities. If the evidence of his qualification thus obtained is insufficient he may be called upon (under para. 10 of Section 4 of the "Directions") to submit to re-examination before his licence is renewed.

The first two years supervision has shown that operators may be divided into two classes; those whose chief aim is to run a regular and reliable service; who have a number of machines in operation, and employ an organised staff of ground engineers; and the owner-operator or small syndicate with one or two machines, whose main object is to obtain the biggest return for their outlay by "joy-flying," exhibition flights, and the like, at sea coast resorts or inland holiday centres. It is appreciated that at this stage the latter class of operator is important from the point of view of the public education in flight. A man who has had one or two short flights during his summer holidays is more likely to consider the possibilities of proceeding abroad by air on business than a man who has never been in the air. It is, however, this latter class of operator that requires the more careful supervision, and it is claimed that the small number of accidents which have occurred have proved that adequate and efficient supervision is possible without undue expense to the State or such a degree of State control as to seriously hamper the operator.

(3) It is of course essential that the supervising inspector should possess knowledge, ability and experience that will convince the ground engineer concerned that the inspector knows what he is talking about, and equally the inspector must obtain the confidence of the operator (*i.e.*, the ground engineer's employer).

The following incidents in this work of supervision may be of interest:—

In one case it was found that the aircraft had sustained considerable damage owing to a bad landing. The operating company executed the necessary repairs, but having no ground engineer licensed in aeroplane construction, borrowed one from another firm. It was subsequently discovered that the ground engineer was licensed only for daily maintenance and rigging of aircraft, and had therefore contravened the Regulations by inspecting such repairs and signing up for these in the log book.

During a visit to another aerodrome the operating company's machine was found to be in a very bad condition, despite which the ground engineer had been issuing daily certificates of safety. On the case being taken up the man's licence was cancelled by the Secretary of State.

A case was discovered of an aircraft flying without a daily certificate of safety being issued, although it was known that the operating company employed a ground engineer. It subsequently transpired that he was engaged on other work during the day, his services as a ground engineer being available only for evening flights, whereas the company operated both afternoon and evening.

In another case an operating company had employed a man who represented himself as a licensed ground engineer; it was found that although he had applied for a licence he had never actually been examined, and had therefore assumed a position for which he was not qualified.

PART IV.

The Duties of a Ground Engineer.

(1) A ground engineer is responsible for maintaining the validity of the certificate of airworthiness, and to do so is required to certify each day on which a flight is made that the aircraft is safe in every way for flight.

The experience during the past two years has been that in some cases there has been a tendency to consider such certificates as merely a piece of formality which must be fulfilled. Certificates have been signed without the ground engineer being in possession of the necessary evidence. When an aircraft has been granted an Air Ministry certificate of airworthiness, has been used in a normal manner, and is reported satisfactory by the pilot, there has been a tendency to assume that all is well, and to certify accordingly without making that careful examination of the machine and that detailed inquiry into what has happened to it since the last examination, which is essential.

The latter point is particularly emphasised. If the ground engineer constantly travelled in the machine he would know exactly what had happened to it and exactly where to look for possible signs of trouble. He could put his finger on defects which many hours of search would not reveal unless their existence was suspected.

Sometimes the ground engineer hands over the machine to the pilot and takes but little, if any, interest in what happens on its journey, although the pilot generally bases his certificate as to fitness for each flight on the ground engineer's daily certificate, and may also rely on the ground engineer to see that the petrol, oil and water in the tanks are sufficient for the proposed journey. The ground engineer is responsible for the airworthiness of the machine until the very moment when it takes the air, and the last few minutes on the ground and the first few in the air often provide evidence which should be carefully noted.

(2) Aircraft, like any other form of transport vehicle, require continuous maintenance, and the ground engineer is responsible that the machine to which the original certificate of airworthiness was granted is unaltered by such

maintenance. He must also consider the conditions under which the machine is stored; how these are likely to affect the various parts of which the machine is composed; he must be familiar with the deteriorating effects of different storage conditions on the various units of the machine, and if he knows that these are particularly deleterious to one especial part, must watch that part and detect the first signs of deterioration that call for its replacement.

The ground engineer must decide when it is necessary to fit a spare part, whether this be a nut or a complete component. The mere fitting of the new part is but the smallest part of this duty. He must satisfy himself that the part has been correctly made in accordance with the drawings on which the certificate of airworthiness was granted, and is of the material specified in these drawings. It must have been inspected during construction (as laid down in detail in paragraph 21 of Section 3 of the " Directions "), and he must have actual evidence that it has passed such inspection, and further, must satisfy himself that the part has not been damaged or deteriorated since such inspection was carried out. A ground engineer might possibly be excused if he failed to discover a hidden defect that had developed in a machine during flight, but there should be no possible excuse for permitting a new part to be fitted into a machine unless fully satisfied as to its history.

(3) The certificate concerning the fitness of the engines is probably one of the most difficult duties of a ground engineer. Obviously the airworthiness of the aircraft depends very largely upon the engines. No one would dream of certifying that a machine designed to use engines developing 300 h.p. each was airworthy if fitted with engines developing, say, 200 h.p. each, yet some have tried to use aircraft when the engines have lost power to such an extent that it has been almost impossible for the machine to take off with its full load.

Records taken over a considerable period show that for every eight forced landings due to engine failure, one is actually due to defect in the engine itself, the remainder being directly caused by some default in the installation of the engine. So long as the engine and the aircraft structure are designed as separate units, installation must remain a weak point of the whole machine, so that the ground engineer must give his constant attention to the daily routine of cleaning petrol filters, checking petrol flows and water connections, etc., ensuring that all ignition leads, switches and contacts are in good order. He should verify each day that the engine runs up to its proper speed, see that the oil pressure builds up and is properly maintained, and that the radiator temperature is normal. He should also make a point of inquiring of the pilot as to any sign of excessive engine vibration in the air, the flexibility of the engine and any unusual circumstances which may have characterised its running during the daily trips. His discretion must be used as to the period of running requiring a top overhaul for cleaning purposes, minor adjustments and replacements, and in due time have the engine removed for complete overhaul. No hard and fast rule can be laid down as to the period of running before top overhauls and complete overhauls should be carried out, since there is still a considerable variation in this respect, even in engines of the same design and origin.

The repairing of an engine requires on the part of the ground engineer in charge of it almost a wider and more detailed knowledge than is needed in the building-up of a new engine, in that he must determine the safe limits to which crankshafts, cylinders and the like may be reground, and the extent to which part-worn components may be retained. A sound knowledge of materials and their heat treatment, too, is essential to justify his responsibility in the acceptance of new parts. This all-round knowledge is not easily obtainable under normal conditions of works organisation and employment. More often than not a would-be ground engineer is found to have excellent experience in the erection and testing of a particular type of engine, but for materials and heat treatment he has relied entirely, and probably quite justifiably, on another department of his

works organisation. So long as he has this other department to fall back on in his supervision of the overhaul of the engine, he is safe, but it is eminently desirable that he should endeavour to improve his own knowledge, and so become self-supporting and capable of carrying through his job on his own, and without the resources of a complete works organisation, which may not always be at his disposal.

(4) One result of both Service and civil experience is that various small points come into prominence which it is desirable to draw to the notice of all ground engineers. " Notices to Ground Engineers " are therefore issued. A list of these publications to date is attached as Appendix II. They are published in the technical press and are sent to all registered owners of aircraft, who are expected to pass them on to their ground engineers. To make certain that they are obtaining these " Notices," ground engineers are required to state that they are in possession of a complete and up-to-date set when applying for a renewal of their licences.

It is here urged that ground engineers and aircraft operators generally should suggest matter for such Notices. Experience with any particular type of aircraft or engine usually brings to light the little troubles to which it is particularly prone. Such experience gained by the larger Companies operating a number of machines would be of value to the owner or operator of a single machine of the same type, and in many cases to owners of machines of similar types, and could often be published as " Notices to Ground Engineers " with advantage.

Occasionally particular points of weakness only become apparent after more or less prolonged use or as the result of an accident. When such cases come to light the certificates of airworthiness for all machines of the type in question are suspended until such time as the defect has been remedied. Information of such suspensions is issued as a " Notice to Ground Engineers." Once the ground engineer's attention has been drawn to a point of weakness it is sometimes possible to permit the aircraft to fly until temporary or permanent replacement has been made without taking the machine out of service.

It is an important duty of the ground engineer to pay particular attention to the terms under which certificates are thus modified, and he must adhere strictly thereto while continuing to grant the daily certificate.

(5) The insurance of aircraft is already of such importance as to call for a separate paper, and on this occasion it is only proposed to touch on one aspect, that of the relation of the ground engineer to the insuring company. So far as the Air Navigation Regulations are concerned, the ground engineer is only required to certify that the aircraft is in every way safe for flight. The risk of insuring any aircraft is governed to a large extent by the following points, all of which have to be taken into consideration :—

(*a*) The design and primary standard of construction of the aircraft.
(*b*) The condition of the aircraft when setting out for the flight.
(*c*) The nature of the flight and the proposed load.
(*d*) The skill and experience of the pilot, particularly with regard to the particular journey undertaken.
(*e*) The meteorological conditions at the time of the journey.

Of these factors the second is that which concerns the ground engineer. It may often, therefore, be his duty not only to maintain that minimum standard insisted upon by his supervisors, but a higher standard which may be laid down by his employers, by the reputation for which they may obtain advantageous insurance terms.

(6) It is suggested that it may be found necessary to consider the formation of a superior grade of ground engineer. It is already probable that a large operating company would find it desirable to place their ground engineers under the control of one man who had higher technical qualifications and ability than are

required for the ordinary ground engineer. Such a man would go far towards ensuring the reliability of any service and would advance the status of " ground engineering " nearer to that which must be attained if these men are to safeguard adequately the aerial transport of the future.

I must apologise for the fact that this paper is so disconnected and inconclusive, my excuse being the fact that ground engineering itself is still in an experimental stage and awaiting its certificate of approval, and in conclusion must state that the foregoing notes and remarks represent nothing but my own interpretation of the regulations and my personal views on the subjects dealt with. They have not been in any way authorised by the Air Ministry, and must not be assumed to be in any sense official statements.

APPENDIX I.

RESULT OF EXAMINATION OF GROUND ENGINEERS.

Categories.	No. Passed.	No. Failed.	Total Applications.
A	139	17	156
B	2	2	4
C	130	31	161
D	12	2	14
A B C D	8	15	23
A B	76	33	109
A C	36	9	45
C D	81	40	121
A C D	18	2	20
A B C	7	4	4
B C D	—	—	—
B C	—	—	—
Totals	509	155	664

Total number of ground engineers licensed to 31/12/20 ... 509
Per cent. operating during 1920 *and under supervision* ... 26%

APPENDIX II.

AIR MINISTRY NOTICES TO GROUND ENGINEERS.

No. 1.—Explanatory Statement.
No. 2.—Petrol-Resisting Rubber Tubing and Connections.
No. 3.—Streamline Wires.
No. 4.—Safety Belts and Harness.
No. 5.—Control Pulleys and Running Cables.
No. 6.—Arrangement of Oil Filter on Aeroplanes fitted with Napier " Lion " Engine.
No. 7.—Avro 504 and 536 type machines: Upper Shoe Fitting for Engine Diagonal Strut (Part 100).
No. 8.—Fitting of Ballast in Aircraft.
No. 9.—Defects in Aircraft Timber.
No. 10.—Foreign Matter in Petrol Systems.
No. 11.—Strength of Control Cables.
No. 12.—Avro 504 and 536 type machines: Upper Shoe Fitting for Engine Diagonal Strut (Part 100).
No. 13.—Handley Page 0/400 Tail Plane Fittings.

No. 14.—Beardmore Engines, 120 h.p. and 160 h.p.
Water Pipe, Part No. 11358/12 B, Connecting the Top Water Rail with the Carburettor Jacket.
No. 15.—Siddeley "Puma" Engines: Disuse of High Compression Pistons.
No. 16.—Renewals of Licences: Complete Sets of Notices Necessary.
No. 17.—Air Navigation Directions Amendments: Authorised Patterns of Log Books to be used.

DISCUSSION.

The CHAIRMAN said it was a pleasure to the layman to read Colonel Outram's paper, which, though technical, was written in untechnical language. It dealt with another form of Government control. They had got so used to Government control that one almost forgot that before the war they had practically none of it. As long as it was directed to something which was thoroughly understood he did not think anyone objected to it, provided it was effective. If it was not one was restive under it. As an example of inefficient Government control he mentioned that some years before the war, when there was plague in India, a system of plague inspection was instituted at Port Said. All the first class passengers were fetched out of bed at six o'clock in the morning, filed in front of a doctor and went back to their beds. It annoyed them very much, as any of them might have been bad with the plague and the doctor would not have noticed it as he did not know their usual appearance. That made them restive and it would be the same with this ground work unless the pilots knew that the inspection was done well and that their safety was insured by it. An inspector who ordered the alteration of controls might be making himself a nuisance, but the pilots would come to respect him, as they would see he was not there just for the fun of the thing. Colonel Outram would be glad to have constructive criticism, and he thought any criticism was likely to be constructive, as the whole thing was so new.

Captain P. D. ACLAND congratulated Colonel Outram on the able manner in which he had dealt with a very difficult subject and on the clear way in which he explained the steps being taken to put in motion the new duties called for under post-war civil aviation.

He stated that he had discussed the whole of this question with his own pilots and engineers at his works, and they all agreed that the work to be undertaken in this new profession was of prime importance. If machines were going to be kept in good order regularity of service is very materially assisted, for after all, if machines cannot fly safely the rest of the organisation would go for naught. In this connection he felt that the actual constructors were bound up with the transport companies at the present time owing to the fact that in the present stage of development the closest liaison between designers and operators was essential if useful types of commercial aircraft are to be evolved.

The question of the certification of ground engineers is one which gives rise to several problems. It is suggested that under existing conditions it is a simple matter for a man to receive a ground engineer's certificate who had had none of the practical experience of aircraft which is considered essential. It is felt that a high standard of knowledge of the art of aviation—that is flying—is more important, perhaps, than that of engineers on a ship. Up to the present, to attain practical training and experience presents difficulties, for men who have been through the shops are possibly inclined to be pedantic with shop practice, and those with only outdoor experience are not sufficiently familiar with the best methods as applied in the shops. It would appear that if many of the fine mechanics who graduated in the Flying Corps had an opportunity of further training in workshops and vice versa, there would be a blend of knowledge which might be useful for future working. The education of future ground engineers

is now receiving consideration and opportunity is being given in universities and elsewhere for furthering this knowledge; in particular, it is reasonable to expect that in time many valuable ground engineers will be drawn from the young men now being trained in the well-equipped establishments being set up for the Royal Air Force.

The inspection of ground engineers and their work is a question which is closely bound up with insurance. It is well known that the airworthy certificate was a minimum, whereas certification should be classified as is done in all forms of insurance.

It has been pointed out that a Government department should not be the only supervisors of ground engineers as they are unable to give a classification and not in a position to state, without some legal ceremony, that one concern is better than another—they can only hold to the letter of the law and classify machines as fit to fly. Efforts have been made and conferences held with the aeronautical inspection directorate to see if a way could be found to alter this, but it had been found to be impossible.

It is felt that possibly a beginning could be made by the creation of a civil organisation which in due course would be run on the same lines as is done in the case of shipping. In this connection a start had been made with an aircraft register and a pilots' register at Lloyds. The point was, had not the day come when a modest beginning might be made by the appointment of, say, one or two inspectors at terminal aerodromes, independent in their duties and responsible to Lloyds, to whom their reports would be presented? From these reports it would be possible for the various risks as represented by machines operated by operating companies, and also the efficiency of their staff and the skill of their pilots to be classified.

He drew attention to the cases mentioned by Colonel Outram where ground engineers' work had been found to be faulty. He would like to have seen also the further remarks as to the action taken in these cases, for there is no doubt that faulty or careless work on the part of ground engineers may very reasonably lead to accidents which did considerable harm to the cause of civil aviation.

Brigadier-General R. K. Bagnall Wild said that the subject of the ground engineer had not been sufficiently ventilated. Technical details might form a useful appendix for Colonel Outram's paper. He thought many of the operating owners of machines scarcely realised the extent and responsible nature of their ground engineer's work, and he was sure a number of pilots were hardly aware of the amount of care and attention the ground engineer gave to a machine. The larger operating companies should shortly have a super-ground engineer of higher capabilities, such as aerodrome manager, to look after the rank and file. It has been stated that the ground engineer was an expensive luxury, but where the ground engineers' work has been good the money spent on them has been saved more than ten times in cost of repairs and fuel per passenger-mile alone, apart from the safety of the public. In his opinion Lloyds should, at an early date, start with one or two inspectors and consider the claim of any operating firm for a rebate off insurance premiums. Many firms ought to get insurance terms at half and sometimes a quarter the present rates, but cannot expect this unless their ground engineers' work is sound and their advice acted on.

The Air Ministry require a minimum of safety, but it is not only that minimum of safety which is being obtained at the present moment; the ground engineers by their efficient work have undoubtedly, in many cases, enabled the machines to be maintained in a greater degree of flying excellence than the minimum required. The operating firms have to look after their machines from hour to hour and minute to minute, especially is this so—as pointed out by Colonel Outram—during the few minutes before flight. No Government can guarantee the execution of such work. It is up to the ground engineer to do his work and up to the operating

firm to employ none but the best, and—a most important obligation—the operating firm must back up the ground engineer in every possible way.

Captain Goodman Crouch remarked that Colonel Outram had dealt more with the ground engineer than with ground engineering. It was not, by any means, an easy job, and, although one could bind the ground engineers by regulations, a great deal remained with them as to adapting an intelligent and keen way of going to work, especially as they were torn between two interests, holding their certificate from the Government and being paid by the firm. As a contrast to that he might mention that during the war he passed out over 500 machines, but there was no difficulty, as everyone was keen to help him. The ground engineer might find it difficult to enforce his opinion. Records obtained by ground engineers should be kept for reference. Ground engineers would like to have the information picked up at other stations. It might be useful to get to know the ordinary life between overhaul periods. It was discovered during the war that certain small types of machine lasted 40 to 45 hours' flying without requiring overhaul, larger ones 60 hours, and still larger ones 90 or 100 hours. That information might be of considerable value to the ground engineer. They were all anxious to get rid of Government control, but in this case it concerned the safety of the public. How could machines be classified into groups for different insurance premiums? Accidents due to structural weakness were negligible.

Lieut.-Colonel Beatty said that the Government must control all forms of public transport sufficiently to ensure the safety of the public.

The lesson learnt from the early days of railways caused such control to be adopted at the inception of civil air transport. The maintenance of the aircraft is probably the most important point to control in air traffic as far as safety is concerned, and Colonel Outram had given a clear description of the system of Government control, which consists in legal compulsion on the owner to employ responsible men of a certain standard of skill and knowledge, whose work is supervised by Government inspectors. Captain Crouch has pointed out the weak point in this system, which is using an employee of the owner as the responsible person.

The only practicable alternative scheme would be to have Government inspectors for each machine, and such a system would undoubtedly tend to kill air transport by overmuch bureaucratic control.

Captain Acland has referred to the desirability of taking drastic action against ground engineers who do bad work.

The Secretary of State has wide powers under the Air Navigation Act, but he would be a rash man who inflicted punishment for infringement of any regulations without *legal* proof of such infringement. No Government department could possibly act in such a manner in England, and the difficulty of obtaining legal proof may frequently enable offenders to escape.

The active co-operation of the industry, and more especially that side of it which is concerned with insurance, will do much to strengthen the present system and to remove any cause for complaint.

Insurance provides a means of rewarding good work by reduced premiums, while punishing bad work by increased premiums or refusal to insure.

He hoped as air traffic develops we should see introduced a system of rebates on premiums where the maintenance work is really good—the ground engineer concerned receiving a share of such rebates.

Such a scheme should result in first rate maintenance with a minimum of Government supervision.

It is possible also that the industry might benefit if owners employed ground engineers recommended by the constructors of the aircraft, and he should certainly

like to see the aerodrome managers of a transport firm holding licences as ground engineers and taking responsibility in questions of maintenance in special cases.

Mr. L. Woods Humphery (communicated):

1. I am sure that everybody in the aircraft industry appreciates the very efficient way in which the examination of ground engineers has been carried out in the past, and it is the earnest hope of all operators that the Examining Board will keep up this present standard and will gradually incline more and more towards the Board of Trade policy in respect of marine engineer certificates until it practically coincides therewith.

2. In part two, can you explain further why those applicants who applied for full licences were only finally recommended as qualified for a licence in only one category, as in many cases it is extremely desirable that a man should have a full licence, as it may save a company sending two or perhaps three men abroad for perhaps a long and expensive journey instead of only one man?

3. Your observations on the difficulties encountered by the Examination Board are only too well appreciated. The ground engineer's position is not a little an anxious one, even from the employer's point of view, as it is almost invariably necessary to use ground engineers as foremen, though one is not necessarily the other. The employer neither wants to run the risk of a crash, which may ruin his business, nor does he want to run the risk of large maintenance bills, which may equally ruin his business.

4. No mention is apparently made of the question of suspension of licence. One would not like to think that a man, having had his licence cancelled, is deprived of all chances of re-employment in his profession.

5. Last, but most important, is one perhaps not definitely applicable to the discussion of ground engineers, but nevertheless it affects them very considerably. The question of basing the depreciation, wear and condition of any aeroplane, engine or parts on the basis of the "hours" they have done in the air. Nothing could be more ruinous practically, in view of the very little experience which anybody has yet in regard to the real life of any of these things.

The Appendix 2 of your paper happens to draw my attention to the one concerning the disuse of the high compression Puma engine; it reminds one also of the Rolls-Royce. I have many figures on this subject, all of which would show without question that the high compression engine of both of these types saves from 20 to 40 per cent. in overhaul costs over the low compression. It cannot be too strongly emphasised that the very greatest care should be taken and the utmost possible evidence obtained before any notices such as the withdrawal of the engine of an aeroplane or part thereof from the approved list are issued. I think I am right in saying that too much evidence is taken at the present from R.A.F. service experience, or from the makers; with regard to the R.A.F. experience, the conditions are, I think, sufficiently different from the commercial as to be almost incomparable. They use higher altitudes, they stunt, and they invariably run their engines on a higher percentage of their full power. Concerning the makers, I do not think it follows necessarily that they know more about their own engines than anyone else, and I am sure it will be agreed that it will be iniquitous to have a system which makes it possible for engine manufacturers, by reason of recommendation to the Air Ministry, to be in a position to enforce the operating companies to entail expenses which may amount to thousands of pounds, without the very fullest investigation from all possible points of view, and the maximum evidence being obtained and published.

General Sir Sefton Brancker said that at first sight the position of a ground engineer under present regulations is an anomalous one, for he is responsible to his own employer and to the Government, and it is conceivable that the interests of each of these authorities might clash. The

only other alternative appears to be to appoint a ground engineer to each commercial aerodrome, who will be the servant either of the Government or of Lloyds. This has several serious disadvantages. When traffic was slack this official would have very little to do; when it was brisk his presence would probably cause delays because he would not be able to clear the aircraft of several companies at the same time. His inspection of the aircraft must inevitably be more perfunctory than that of a man who is not only responsible for the fitness of the aircraft to fly, but is also probably in charge of its actual maintenance. Further, a cautious official, in order to avoid responsibility when in any doubt, would refuse permission to fly, whereas a ground engineer whose interests lay with the welfare of his own company, as well as with Government regulations, would be more broad-minded.

He was of opinion that the present system is probably the best possible under the circumstances. An efficient company which is running a service in the best interests of the public would be only too glad to accept the supervision of a really good ground engineer whom they know and trust. It is probable that any clashing that may occur between the allegiance to the Government and the allegiance to the employer will be the result of inefficiency on the part of the company.

He would like to emphasise one point that the lecturer makes—that out of every eight forced landings, due to engine failure, seven are the direct result of faulty installation. It is in perfecting our installation that we must concentrate our efforts for the moment in order to make aerial services more reliable. He always contended that we have brought the engine and the aeroplane to such a pitch of perfection that with proper supervision engine failure need never occur, but installation still leaves much to be desired.

Mr. Woodis Rogers: I must confess to being disappointed with this paper because, not having read an advance copy of it, I was misled by the title into supposing that it referred to engineers.

I think the whole principle upon which this system is based is wrong, as it puts the onus of inspection on the Government rather than on the individual who owns the machines. It necessitates a large number of inspectors who deteriorate in quality as they increase in numbers, and they appear to be mechanics of the "sticky tape" variety. This gives far too much power to uneducated men and must create a very heavy burden for civilian flying to carry in the way of unnecessary obstructions.

It should be quite unnecessary for a Government official to inspect a machine before every flight. This duty should be carried out by the owner of the machine, who should have an engineer responsible for this work in his own employ, who would work in close conjunction with the pilot in rectifying any fault which they notice.

This would reduce the number of Government inspetcors very considerably and they could be men of high qualifications of similar standing to Board of Trade marine inspectors. These inspectors would periodically visit aerodromes and inspect machines. If any case was found where the machines had not been maintained in the condition in which they were when they were passed originally, the owner of the machine should get into very serious trouble, such as something to do with "boiling oil."

This would put the matter of inspection on similar lines to the Board of Trade in relation to ships, where the onus of maintaining ships between periodical inspections rests with the owner.

It is obvious that it is to the interest of the aircraft owner, even more than in the case of a ship owner, to maintain his machine in a safe condition, as any accidents must be very prejudicial to his business.

COLONEL OUTRAM'S REPLY TO THE DISCUSSION.

The discussion has proved my contention that misunderstanding exists as to the duties and responsibilities of the ground engineer, and has brought forward a number of interesting points.

Captain P. D. Acland, while agreeing that it is essential to maintain a high standard when examining for licences, at the same time recognises the present lack of men with all round knowledge and ability.

The "endorsed" and "limited" licence has been introduced to meet these temporary conditions. It is hoped that in the future an "unlimited" licence will be the rule rather than the exception.

His question as to the action taken when a ground engineer is found to be doing indifferent work had been dealt with by Colonel Beatty.

General Sir Sefton Brancker's opinion that it is probable that a clash between a ground engineer's allegiance to the Government and his allegiance to his employer (which some people seem to think inevitable and an inherent defect of the present system) will occur only in the case of the inefficient company, is most encouraging. It has always been my personal belief.

Major Humphries touches on the "limited" licence question. I would emphasise that a licence is only "limited" when a man's experience is so limited as to be insufficient to qualify him for a full licence. He points out that no mention has been made of the suspension of a ground engineer's licence. Should supervision reveal that a ground engineer is unqualified, the licence must be cancelled, since obviously an unqualified man cannot be licensed until he has obtained such additional experience and education as will make good his deficiencies. On the other hand, faults or failures other than those due to ignorance or incompetence might well be dealt with by suspension.

Mr. Woodis Rogers' notes are typical of the misunderstanding that exists. He states that he considers that the whole principle upon which the system is based is wrong, and then proceeds emphatically to urge a procedure identical with that at present in use.

In conclusion, I would urge that some means of collection, collation and interchange of information between ground engineers is most desirable, and in fact an urgent necessity.

I would like to suggest that this is a function which might well be undertaken by the Royal Aeronautical Society.

Votes of thanks were accorded to the Lecturers, on the motion of the Chairman, and to the Chairman on the motion of Colonel the Master of Sempill.

THE TECHNIQUE OF FLIGHT.

Lectures delivered to the Scottish Universities in November, 1920,

BY SQUADRON LEADER R. M. HILL, M.C., A.F.C.

Flying is an art. A pilot may actually fly a small manœuvrable aeroplane of the present day without knowing much about aerodynamics, just as a musician may draw exquisite music from an instrument without a knowledge of the laws of sound. There is a flying instinct just as there is a musical instinct; an unerring perception of the modes and measures of the art; a subconscious obedience to laws which are at most but dimly realised. I do not say that a pilot can *design* a successful aeroplane without a certain knowledge of the fundamental truths of aerodynamics, of the distribution of stresses in a structure, any more than a musician can compose a sonata without a knowledge of the laws of sound, the laws of harmony and counterpoint, the practice of great masters in the traditions of sonata writing; but I do maintain that he can *fly* the aeroplane. I further maintain that flying demands men of a certain temperament, that in general the temperament of a successful pilot veers rather towards the artistic than the scientific, and that these two temperaments are in most ways opposed to each other. I think it is an undisputed fact that men of scientific temperament seldom make good pilots, and that is the pity of it; for if they did make good pilots the advancement in design of the heavier-than-air machine would be far more rapid than it is.

In these two lectures I am only going to deal with craft which are heavier than air. Hitherto the evolution of their design has to a large extent been based on the accumulated observations of flying men; the "hit and miss" method if you like it. The pilot looks at the behaviour of his aeroplane in the air subjectively, and often it appears that there are nearly as many flying qualities in an aeroplane as there are pilots, who, in other words, frankly disagree about its flying qualities.

In trying to formulate conclusions which shall have a wide application investigators are confronted with a chaos of flying opinion; general conclusions take long to form, and even then have to be accepted with the greatest caution. As long as the pilot has definitely to control his aeroplane by the "feel" of it, as we say, so long will flying remain an art.

I have mentioned the word "feel." Let us get quite clear in our minds about that word. "Feel" is the reaction to the force that the pilot exerts to control the aeroplane, and his perception of the position of the wheel or bar or whatever machinery he uses to exert control. One is not enough without the other. If I turn an aeroplane control wheel round, I perceive how far round I have turned it and the amount of force I am using. Now why do we want to be able to feel the aeroplane, as the rider feels his horse's mouth? A ship is steered by mechanical means and the helmsman follows his compass. Would it not be far simpler if we could rid ourselves of the capricious human element and reduce the control of an aeroplane to a series of mechanical operations? Anyone can see that it would, but let us face the facts and see what is involved.

Anything which is propelled by machinery or natural forces and directed by a human being has some form of controls. The sheets of a sailing ship, the steering wheel of a car, are controls. The tiny skiff is directly controlled by the

man and he has the direct feel of the rudder. As the boat becomes larger the rudder becomes heavier; and if the man is not strong enough to move it he employs a form of gearing. The larger the ship the more sluggish are its movements and the less is the strength of a man relative to the power required for control. Finally, the big ship is controlled by a steam gear and the "feel" is gone. Thus we see that relative size is one of the factors which will measure the desirability of "feel."

But an aeroplane moves in three dimensions while a surface ship only moves in two; the control of an aeroplane is then far more complicated than that of a ship, far more, I should like to say, than in the ratio of three to two. Not only this, but an aeroplane is supported by an element many hundred times less dense than a ship; and although as aeroplanes become larger with increasing moments of inertia the tendency is for "feel" to be less and less desired, I consider that no aeroplane of the sizes reached to-day, or likely to be reached in the near future, will justify the exclusion of "feel." The time factor is too important, the supporting element too tenuous, too elastic, the movements of the aeroplane too sensitive, the need for delicate exactitude so vital, that confidence of the pilot in his controls lies above all in "feel."

I have said that "feel" is the perception of the force on the control and the position of the control mechanism; but that is not all. The pilot moves the control mechanism and judges with his eyes the resulting motion of the aeroplane. That is another factor in control. Since movement involves acceleration, the pilot will feel it in his body. Normally he feels his own weight, or gravity acting on him; if he imparts to the aeroplane an acceleration, the force on him, or apparent gravity, may be increased or decreased. Everyone knows what it is like when a lift starts to move up or down. In some manœuvres this force may rise to as much as four times gravity. This is another way that the pilot has of judging the effect of his control movements. The last way is by means of his instruments; these usually consist of an airspeed indicator, an aneroid barometer, a compass, a lateral bubble, and only too seldom an instrument called a turn indicator. In short, the pilot flies by "feel," by optical perception of the aeroplane motion, by the apparent force of gravity, and by his instruments. By none of these in themselves can he safely control the aeroplane under all conditions, and by the loss of any, at least in the present stage of development, his control is impaired.

Let us subtract them one by one and look at the result. I have already indicated the loss to the pilot if his "feel" is subtracted. Now preclude him from observing the motion of the aeroplane with his eyes, in other words put him into a thick cloud. Many of you, if you have not flown, have walked up a mountain side through a cloud, and you know what it is like. Without his eyes the "feel" and apparent gravity are of comparatively little use to the pilot and he relies on instruments. Nowadays I am glad to say that they have been so developed that a pilot can maintain the aeroplane on a reasonably good course and in steady flight, provided he is at a safe height above the ground; but he dare not approach the ground nor try to land on it, mainly because his aneroid barometer only shows him a relative height and not the actual height above the ground he may be over at the moment; and because, if it did, it would not be sensitive enough to make safe landing possible even if the pilot had any means of telling if the ground were suitable for landing. Therefore the loss of the pilot's optical sense of the movements of the aeroplane is not satisfactory under all conditions.

Now imagine, if it were possible, that the pilot could rid himself (which of course in practice he could not) of the changes in apparent gravity. I do not think he would lose very much, though to a skilled pilot the changes in these forces are in some ways helpful. Lastly, make him fly without instruments. The early pilots did this by force of necessity, but no one would think of doing so now, and it would be impossible to fly through clouds,

Take a submarine. This is a craft which moves in three dimensions, just as an aeroplane does. The submarine commander has to make rapid decisions when his craft is near the bottom in order to avoid hitting it hard. I believe that in these sort of circumstances there is always a desire for a direct form of control; the engine-room telegraph begins to feel too cumbrous for the man's nerves keyed up and waiting for the response. Now an aeroplane, because it goes much faster, may be approaching the ground ten times as fast as the submarine approaches the bottom. Do you wonder that the pilot wants to have the "feel" of the controls and his fingers on the pulse of the engine?

A pilot must not be a slave to any one of these methods of perceiving the motions of his aeroplane consequent on his control; he is most likely to worship his instruments, and he may suffer a bitter disillusionment one day if they show incorrect readings. His senses, his reason and his instinct must balance up his fleeting perceptions and assist him to form his judgment of the right things to do. It has been noticed that in some manœuvres the pilot may be subject to large and extraordinary forces, forces which a person scarcely ever feels in ordinary life, and these must have their inevitable physiological reaction on him. They may give him some indication of what the aeroplane is doing, but they may also make it difficult for him to exert himself physically and mentally.

If his hand feels three times as heavy as in normal life it is more difficult to move the controls sensitively; and if his head feels crushed into his body his reasoning powers are not enlivened. Luckily the large forces on the pilot are not usually long sustained in practical flying, so that the physiological effect is not serious; if they are they do actually occasion some considerable risk, as in a long spin.

The controls of an aeroplane are necessary to take it off the ground, to climb it, to fly it level, to manœuvre it and to land it. Suppose that the instant the pilot ceases to control the aeroplane it is upset by a gust and falls over sideways, or plunges downwards, or sits on its tail, as we call it; you can imagine what a mental strain it is flying such an aeroplane, hour after hour, through wind gusts and foul weather. If physical effort is involved in the control, as it is in the larger aeroplanes, it is a physical as well as mental strain.

Thus at some time or another a widespread desire began to make itself felt for what is termed stability; that an aeroplane should look after itself to some extent; that it should not behave like a floating barrel and tip over if you sat on it, but rather as a pendulum behaves and return to a stable condition if left alone by the pilot. An aeroplane would be completely stable if it would right itself from any position it might have got into owing to a gust or even deliberate action of the pilot. It would always require some space to right itself, and some time; the quicker it would right itself the more stable it would be said to be. The process of righting itself nearly always involves the loss of some height, so it is safer to fly well clear of the ground, for if you upset near the ground you may strike it without a chance to recover. A pilot gets to know particular types of aeroplane and their characteristics; with some he will carry out daring manœuvres comparatively close to the ground, because he knows that they do not take much space to recover in case of an upset; with others he is extremely cautious and allows himself much more space or height. Many valuable lives have been lost through the ignorance or carelessness or deliberate risk taken in this way.

You will now see what I have been telling you about has been concerned with control and stability, the two most important things to a pilot from the point of view of safety. The pilot thinks more about these subjects than anything else, as they are ever present problems to him. I shall have more to say about them later, but before proceeding further I want to go back to the beginning. If a man is going to learn to fly he ought to know why his aeroplane rises into the air and what keeps it there. That sounds simple enough, but most accidents arise from

a disobedience, whether conscious or unconscious, of fundamental laws. Most of you are probably familiar with the broad outlines of aerodynamics, some of you have doubtless gone more deeply into the subject. Will you pardon me if I just look at it from the point of view of the pilot who has to fly and dwell on a few truths which essentially concern him in the art of flying his aeroplane.

I will assume we are going to fly a standard tractor biplane, which has a fuselage or body with an engine and propeller in the nose, two sets of main planes one above the other and a tail plane behind. It has, of course, an undercarriage with a pair of wheels on which it runs along the ground before rising and after landing.

Now it is obvious that an aeroplane will not stay up in the air unless there is some force keeping it up and counteracting its weight, which is all the time dragging it down. This force is, as you know, the result of the passage through the air of the aeroplane's inclined wing surfaces, which give a downward motion to the air over which they have passed. The quicker the wings move through the air the greater is their lift, and conversely the slower they move the smaller is their lift. The lifting force depends on the angle of the wings to the relative wind, that is, their angle of incidence; on their size and on their velocity relative to the air; if the angle of incidence, as it is called, is kept the same, the lifting force is proportional to the square of the speed. If you know what the lift of the wing is at one particular speed you are enabled to say what its lift will be at other speeds, and you can plot a series of curves showing lift against speed at various angles of incidence. I spoke a moment ago of relative wind. I do not mean the wind we experience when we walk down the road. Suppose you are sitting out on the wing of an aeroplane, you will obviously feel a wind whistling past you even though in the ordinary sense there is no wind blowing. This current of air that you feel we call the relative wind, and its speed is of course equal and opposite to that of the aeroplane through the air. But if there is an actual wind blowing in the opposite direction to that of your flight your speed over the ground will be your speed through the air minus the speed of the wind. If your airspeed is 100 m.p.h. and the speed of the wind against you is 30 m.p.h., your speed over the ground will be 70 m.p.h. Conversely, if the wind is with you, to get your speed over the ground, you have to add the wind speed to your airspeed.

Now before an aeroplane can rise into the air the lift on the wings must be greater than the weight of the aeroplane or otherwise it would not start to rise. Pilots do not always realise this, especially when learning to fly, and try to use their controls to get off too soon, with unpleasant results. So you have got to run along the ground first, and opening out your engine to full throttle, gradually run faster until a certain speed is reached, usually about 45 m.p.h., when the lift becomes equal to the weight. After this speed has been passed the lift on the wings can overcome the weight of the aeroplane and lift it into the air. It is obvious that the weight is fixed, so the lift you want is fixed; and in consequence of this, for steady flight there is only one speed possible for a given angle of incidence. When you are getting off the ground a time comes when you realise by the feel of the aeroplane that it is entirely air-borne.

If when you get off you fly steadily in one direction you may climb to a certain height, fly level at that height, and then glide down again. In each case your lift will just balance your weight, and it will be the thrust or pull of the propeller which will settle whether you go up, level, or down. Now you have got to employ a certain amount of power in overcoming the air resistance, and the faster you go the greater is the power required in doing this. You know the great amount of resistance that the air offers to any large surface when you try to push it quickly through the air. Go outside and try and run with an open umbrella in each hand; then imagine what it would be like to drag forty umbrellas

along, and think what it would be like to drag them ten times as fast, when you would have to pull a hundred times as hard. The force required to drag an aeroplane through the air would be as great as this, were it not that the wings are so shaped as to get rid of as much resistance as possible. Even then engines of three and four hundred h.p. are in common use to-day.

In addition to the resistance of the wings there is the resistance of the body, the wires, the struts, and the undercarriage. You know how every effort is made to streamline these to reduce resistance. The opening in the body where the pilot sits makes a tremendous amount of resistance alone; even the wheels have covers; and all projections, where they cannot be eliminated, are carefully faired off.

But what is the effect of the air resistance which inevitably remains after the maximum possible reduction? As was shown before, the resistance requires a certain amount of engine power to overcome it, and the greater the speed of the aeroplane the more it requires. The only limit to the speed is when all the power the engine will give is used up in overcoming the resistance. We have now arrived at a definite speed range for the aeroplane in level flight. It can go no slower than the lower limit, neither can it go faster than the upper. A frequent speed range of to-day is from 45 m.p.h. to 120 m.p.h., which is very large compared with older aeroplanes that frequently had a range of from 40 m.p.h. to 70 m.p.h.

It has now been demonstrated how fast the aeroplane can fly and why it can fly no faster. What happens if it is flown rather slower than its top speed? It would then have a certain power reserve, as the resistance is not so great as at top speed. What can be done with this reserve? It can be used for climbing. The greatest rate at which you can climb is settled by the size of this power reserve. I will show you a curve soon which will demonstrate this reserve pictorially. If you increase the power, you have a greater reserve for climbing or you can use the extra power to increase the top speed.

Again, suppose the engine to be shut off. If the aeroplane does not maintain a certain minimum of speed, it will fall down rapidly; so the only way of maintaining this speed is by going down hill or gliding, that is, by using gravity as your motor. A glider, of course, uses this means of propulsion.

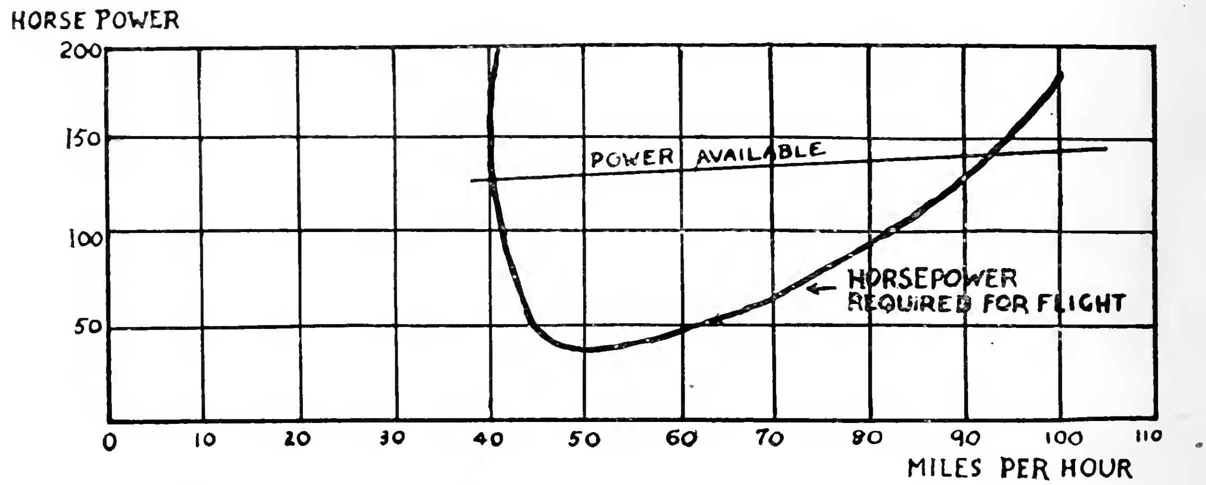
Let me now take a homely comparison, namely, the bicycle, which serves rather well to illustrate what flying is like; you will see how you have to obey similar laws in both cases.

The starting, climbing, flying level and gliding of an aeroplane are very similar to what happens on a bicycle. Before you can start on a bicycle you must get up a little speed or you will fall over. When you have started you must imagine yourself to be the engine. You are on a level road and you pedal harder and harder and gain speed until a limit is reached where you can go no faster. Then you are exerting all your power in overcoming the resistance of the wheels on the ground and the air resistance.

But now if you go rather slower than that, you will have a certain amount of reserve power which you can use when you come to a hill, and the steepest hill you can climb depends on the amount of reserve power you have, in other words, how strong you are. When you are climbing as steep a hill as you can you may be only going 6 or 7 m.p.h., while on the level you go 16 or 17 m.p.h.; just the same happens in the aeroplane. When it is climbing steeply it goes forwards at about 60 m.p.h. while on the level it might be able to do 120 m.p.h.

Then on a bicycle, if you stop pedalling, which corresponds to shutting off your engine in flight, unless you can maintain your speed you will fall off, and you can only maintain your speed by free-wheeling down hill, which corresponds to gliding. On both bicycle and aeroplane, the steeper you come down the quicker you go.

We have now seen how an aeroplane maintains its flight and does not fall suddenly to the ground when the engine is shut off, but glides down steadily; it certainly does not behave in the way described by the American gentleman who assured an old lady that there were hundreds of gallant aviators dying of starvation up in the sky, whose engines had stopped by mistake and who consequently could not get down.



HORSEPOWER AND SPEED FOR LEVEL FLIGHT.

This figure refers to an aeroplane weighing approximately 1,500lbs., and shows a curve representing the h.p. that an engine suitable for driving it would give near the ground at various speeds. You see that the h.p. available goes up a little as the speed rises owing to the increased engine revolutions and the increased efficiency of the propeller. The other curve shows the h.p. required to fly the aeroplane level near the ground. You will see that this particular aeroplane cannot fly at any speed below 40 m.p.h. where the curves intersect, and cannot fly faster than 93 m.p.h. where they again intersect. The curves for any other aeroplane would be similar in shape to these ones.

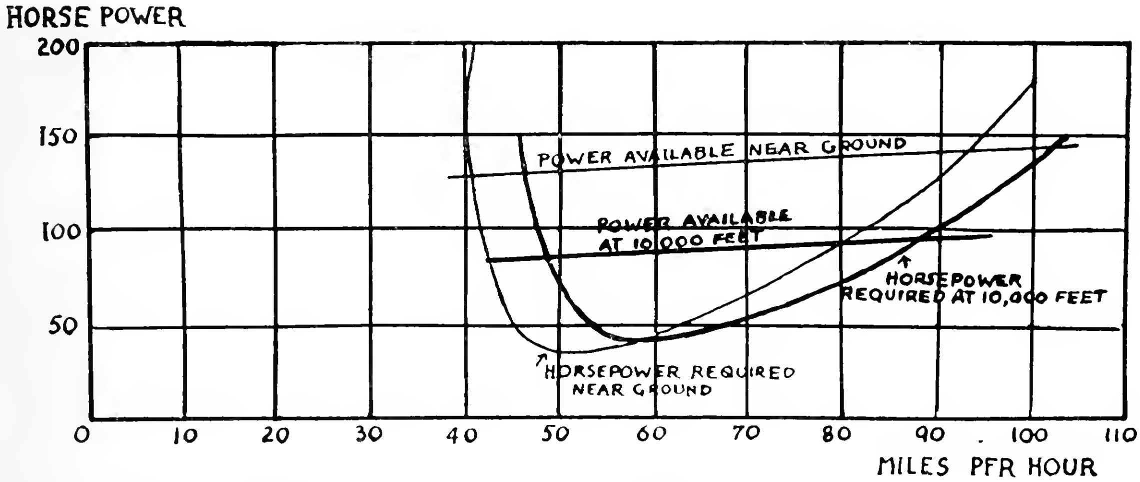
I am not prepared to go into how these curves are arrived at. For students of aerodynamics there is no better book than Professor Bairstow's.

The curves, however, show pictorially what I have been talking about, and you can see quite plainly the reserve of power at any speed which you can call on simply by opening the throttle wide and which can be used for climbing. You can also see the large range of speed from zero at which flight is not possible. It is through trying to fly near the ground in the latter area that 80 per cent. of aeroplane accidents happen. It is interesting to notice that in this aeroplane the minimum power requirement occurs when you fly near 50 m.p.h. You need actually more power at a lower speed, such as 45 m.p.h.; that is why you climb best at a speed rather above your lowest speed, because you have the largest reserve of power. Every pilot is interested in knowing the best forward speed to climb his aeroplane at, in order to rise quickest. However, in practice you have a certain latitude in the speed you can choose; and if it is a little higher than the theoretically best speed, the rate of climb is not reduced very much.

We are now dealing with points which affect the economics of flight; this subject does not so vitally concern the war pilot, because the conditions of his flight are usually dictated by other and more urgent reasons, such as freedom from annoyance by anti-aircraft fire, or the necessity for shooting at troops on the ground; but it does come in where flying has to be made to pay, and the question of the cost is ever present. From looking at these curves you will see that it is obviously the most economical to fly near the speed at which you need minimum h.p. and use least petrol. In this case it is in the neighbourhood of

55 m.p.h. But if you are flying from London to Paris you may encounter adverse winds of 20 m.p.h. and upwards. This would reduce your ground speed to 35 m.p.h. and you would take an absurdly long time to get there. Therefore it would not pay to fly so slowly as this. These are some of the things you have to think of in weighing up at what speed it is most economical from all points of view to fly.

Now I will show you another figure, which is simply the last one with a second set of curves introduced.



EFFECT OF HEIGHT ON THE SPEED OF FLIGHT.

The curves show the change in conditions when you have climbed to a height of 10,000 feet. At this height the density of the air is about three-quarters of the density near the ground, and as you go higher still, the density decreases more and more. You will notice that the curve of h.p. available at 10,000 feet has come down; in other words, as you climb higher the h.p. that the engine can give at full throttle falls off. It is easy to see why this is so. The power developed by an engine at each explosion is roughly proportional to the weight of explosive mixture. To obtain good results this must always be kept in a certain ratio of petrol to air, I believe about 1 : 15, therefore the power depends on the weight of air sucked in at each suction stroke. As you climb higher and the air becomes less dense, less weight of air can be sucked in and therefore less petrol, so the power falls off. At the present time experiments are being made with super-chargers, which deliver air to the intake under pressure and put in more weight of air at each stroke, thus mitigating to some extent the effect of the reduced density. In America an extraordinarily successful climb was made by Major Schroeder to over 30,000 feet, using a supercharger.

But you see that not only has the power available curve come down, but the curve of h.p. required to fly at 10,000 feet has been displaced to the right. Again I do not propose to enter into details of arriving at the curve, but in a general way, without much thought, you can see why this is so. You will notice that the new point of intersection showing the lowest speed is nearly 50 m.p.h. instead of just over 40 m.p.h. This is because the air is rarer and cannot support the weight of the aeroplane at such a low speed. In spite of this the top speed is actually reduced and the speed range narrowed down. There must come a time as you go higher and higher and the engine power falls off, when the curve of h.p. required will only just touch the curve of h.p. available. We call this point the ceiling of the aeroplane; after that it has insufficient power to climb any more at whatever speed it is flown; in fact the speed range has gradually been narrowed down till it does not exist, and you have one speed of flight lift which will just maintain you at your ceiling.

The curve of h.p. required to fly at 10,000 feet is plotted on the basis of true speed. As a matter of fact the pilot's airspeed indicator would not show this speed at 10,000 feet.

As the aeroplane travels through the air, the air blows into the pressure head, which has an open end, and the instrument simply shows a difference between this pressure and the static pressure, that is, the pressure that an ordinary barometer would record by means of a pressure gauge. The pressure head is connected to one side, and the static head, which has a closed end with little holes drilled round the side, to the other. As you climb higher the air, as we saw, becomes less dense and blows in less hard, so that the instrument reads low. At 60 m.p.h. indicated near ground level the reading falls off roughly at the rate of one mile an hour for every thousand feet climbed.

You would not try to fly the aeroplane to its ceiling unless you were out for an altitude record, as it feels too uncomfortable on the controls. When you carry out performance climbs you usually break off when the aeroplane climbs no faster than 100 feet per minute, and this is usually termed its "service ceiling," in other words, its "ceiling" for all practical purposes.

Now observe another point. It pays to fly high because, neglecting the lower speeds, you actually use less power at a given speed. At 80 m.p.h. near ground level you are using about 95 h.p., whereas if you flew at 10,000 feet you would only use about 70 h.p. to support your given load, which means you would use less petrol. The curves also show that by flying high, apart from the very greatest speeds attainable near the ground, you can either fly at the same speed, that is, do the journey in the same time and use less petrol; or use the same amount of petrol and do the journey faster; or you can do anything between this, saving a little time and a little petrol.

However, in civil aviation aeroplanes will probably not be flown very high, because the passengers will get cold bodies and perhaps cold feet! Notice that when you are using 70 h.p. at 10,000 feet flying at 80 m.p.h., you actually have about 95 h.p. that by opening the throttle wide you could use. This means that you actually throttle your engine down and use it as a lower powered engine. It is one of the most important concerns of every pilot to husband his petrol supply as much as he can.

I will again point to the curve for h.p. required at 10,000 feet, and demonstrate how it can be used in another way. Its use is only approximate, but will serve for the purposes of illustration. It shows you what is the h.p. required to fly the aeroplane near the ground level if you cut down the wing area so as to increase the loading in pounds per square foot. This curve was arrived at on the basis that the air was about three-quarters as dense as that near ground level. It will now show what happens if you were to cut down the wing area of the aeroplane by a quarter, and increase the loading, say, from 6 to 8lbs. a square foot. Economically the same arguments apply as in the case of flying high. As you are supposed to be flying near ground level you must use the h.p. available curve for ground level in conjunction with the curve for increased loading. It pays to fly high or with a heavily loaded aeroplane; the aerodynamic effects are the same. The slowest speed has gone up, but in this case the top speed has also gone up. You use less h.p. to fly at 80 m.p.h. with the heavier loaded aeroplane. As a matter of fact you save a little weight in cutting down the wings, and this weight can be utilised for useful load. As it is obviously economical to fly with heavy loading, where does the limit come? The minimum flying speed goes up, that is, you want more speed before you can rise off the ground, which means you have to take a longer run to get off. Again, the safe speed at which you can land goes up, and consequently you run farther after landing, which makes it increasingly difficult and dangerous. The great motto of civil flying is "Safety first"; this is where safety and economy are opposed.

I have outlined in a general way the pilot's control of his aeroplane; the help it certainly gives him if it is stable; the way in which it rises and maintains itself in the air; its performance under various conditions, and the most economical way in which it may be handled. I now propose to return to the questions of control and stability, which continually crop up and vex us.

Control and stability mutually react on each other; you can see that if the aeroplane possesses aerodynamic properties which enable it to look after itself, they must, if only to a small extent, run counter to the pilot when he wants to change its attitude rapidly; but more of this later.

The first crude aeroplanes came into being in a haphazard way, and most of them possessed in a high degree the negative quality of instability. It was not till long afterwards that the positive quality of stability was evolved. The maintenance of equilibrium in these early aeroplanes depended entirely on the skill of the pilot, and many an enthusiastic pioneer sacrificed his life in this way. Previous mathematical calculation was of little use, and the only way to develop aeroplanes was to take them up and try them. I sometimes try to figure to myself the skill, the pluck, the optimism and the enduring faith in the future of the aeroplane that inspired the early pioneers to carry on in spite of disappointment and often physical injury, and in an atmosphere very often of intolerance and ridicule. They did go on, and their trials and errors have left us the great legacy we have to-day.

The difficulties which enfold the problems of flight are the elementary difficulties of grappling with them, of stating them properly, of giving the scientist a fair road to work on. Would-be investigators floundered in a sea of ignorance; therefore the most fruitful course was to take machines up and try them, to form conceptions of experiment in the climax of an unsuccessful manœuvre, not to rely too much on the testing out of preconceived theories manufactured on the ground. Experiments had to be kept fluid; methods constantly adapted to the revision of fundamental ideas; the whole process constantly stimulated by the ever increasing mass of air experience.

The flying qualities of an aeroplane had first to be experienced as it were by chance; the pilot had to make a steep turn before he knew what he desired of a rudder. The Wright Brothers, I think, really laid the foundation of the modern aeroplane when they enunciated that for three-dimensional control you needed a rudder to steer sideways, elevators to make the aeroplane go up or down, and a form of lateral control by warping the wings which made possible correctly banked turns. Even then the flying qualities of the early Wright aeroplanes must have taxed human skill to the uttermost in satisfying the elementary requirements of flight; but they definitely proved that power-driven flight was a practical possibility, not a wild dream. As I said, the form of their control surfaces, with the exception of warping wings which have been superseded by ailerons, is with us to-day; even the principles underlying the use of ailerons differ in no way from those of warping wings.

The control surfaces vary, of course, in all the different types, but their use is the same. The control stick, which is universally pivoted, is arranged between the pilot's knees, and if he moves it backwards and forwards he raises or depresses the elevators; if he moves it across from side to side he raises one aileron and depresses the other. His feet are placed on the pivoted rudder bar; if he rotates the rudder bar he moves the rudder across. He pushes with the right foot to make the aeroplane turn to the right and with the left foot to make it turn to the left. Similarly, he pushes the control stick forward to depress the nose of the aeroplane and pulls it back to raise the nose; he pushes it to the right to tilt the starboard wing down and to the left to tilt the port wing down. You see the motions of the control mechanism are made so that under normal conditions of flight they correspond with the pilot's observed motion of the aeroplane. There

are certain abnormal conditions of flight in which they do not correspond, and this is where the pilot always goes wrong when he is learning the art of flying, and where he is liable to go wrong even when he is more experienced.

Now besides the aeroplane controls you have the throttle of your engine, the entire business of which is to vary its power. The throttle lever is usually placed on the left side of the pilot's seat, so that he uses it with his left hand while his right hand holds the control stick. What a pilot soon realises when he begins flying is this, that he is entirely at the mercy of his engine if he wants to remain in the air. He may have once or twice tried to remain too long in the air when his engine is failing and come down with a crash. It is really surprising how easy it is to forget this point when you are in the air. You are getting off the ground and have to pass over some obstacle; in the meantime your engine drops power and you still manipulate the aeroplane controls as if it were giving its full power; I have seen dozens of people do it; it nearly always ends in a wreck even if the pilot is lucky enough to escape with a few bruises. We have seen that if the pilot shuts off the engine he must at once commence to glide down or otherwise the speed drops and the lift will not remain equal to the weight; similarly, if the engine shuts itself off owing to a choking carburettor or an obstruction in the petrol system, he must also commence to glide. What is he to do if he is going for a shed and cannot get over it? Well, that is why flying is not always an easy art.

If the engines of a ship stop there is usually some time before any danger need be anticipated. She may drift off her course and finally go ashore; but if the engine of an aeroplane stops something drastic has to be done at once or else considerable danger immediately arises.

Every day the power plant is being made more reliable, but I am sure it will be some considerable time before the standard of reliability of the locomotive or steamship can be attained. The aero engine has to be built so lightly; it is so comparatively frail for the work it has to perform; there is so much vibration of the parts, owing to the lightness of build, that the measure of reliability attained to-day is more the result of sheer ingenuity of design than of solidity and a big margin of strength. The pilot has not got to the stage where he can place implicit faith in his engine, and he must be ready, if only subconsciously, for a possible failure.

Please do not misunderstand the spirit of my remarks on this point. Superficially it appears that the art of flying is beset with lurking dangers. Difficulties only exist to be overcome; but in order that they may be overcome their extent and significance must be unemotionally analysed. Real risk only exists when it cannot be foreseen and eliminated by the pilot. So, if as well as flying skilfully, a pilot wants to play his part in assisting the development of the aeroplane, to fly intelligently; then I am sure that the value to him of a sound grip of engineering principles is incalculable. Truths that he has assimilated during an engineering training, the value of which at one time may have seemed obscure; these will come back to him when he has to test new types of aeroplane with difficult problems of control; will light him on his way; will, as it were, watch over him and guide his judgment. In my next lecture I shall endeavour to show how nearly all the dangers of flying not only can be, but are successfully met and overcome by the pilot who flies with his weather eye cocked open.

(To be concluded.)

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All communications should be addressed to the Editor.

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Notices of the Royal Aëronautical Society.

Election of Members.

The following members were elected in the various grades as shown at a Council Meeting held on May 17th:—

Fellows.—Commander F. L. M. Boothby, R.N., Captain S. W. Hiscocks, J. L. Pritchard, Colonel E. W. Stedman, A.M.Inst.C.E., A. J. Rowledge, M.I.Aut.E., A.M.I.Mech.E.

Foreign Members.—Major H. R. Coningsby, K. Hashimoto.

Associate Member.—F. H. Bullock.

Students.—F. G. Ping, G. W. Worsley.

Safety and Economy Committee.

The Safety and Economy Committee held its last meeting on Friday, May 6th, when the report was finally approved. It is now in the printers' hands and will shortly be issued as a pamphlet, price one and sixpence a copy.

It will be remembered that this Committee was constituted as follows:— Lieut.-Col. M. O'Gorman (Chairman), Lieut.-Col. W. A. Bristow, Lieut.-Col. L. F. R. Fell, Capt. G. de Havilland, Capt. G. T. R. Hill, Wing Commander J. H. A. Landon, Sqdr. Ldr. G. H. Norman, Mr. H. R. Ricardo, Mr. A. J. Rowledge, Col. F. Searle and Mr. R. McKinnon Wood.

Owing to the number of external conditions which would have to be taken into account in considering a 500-mile route, the Committee ultimately limited its deliberations to the type of engine and mechanical arrangements, etc., required for the safe and economical working of an aeroplane carrying mails and passengers between London and Paris.

Pilcher Memorial Prize for Students.

The Council is glad to be able to announce, through the kindness of a gentleman who desires for the moment to remain anonymous, the offer of an annual prize to the value of £5 for the best paper prepared by a Student Member of the Society initiating discussion at a Students' Meeting during each year. This prize will be known as the "Pilcher Memorial Prize for Students," in memory of the late Percy S. Pilcher, who was a Member of Council of the Society from

1897 to 1899, and whose gliding experiments are recorded in Volume V. of the "Aeronautical Classics."

Mr. Pilcher was a naval architect by profession, being Assistant Lecturer in Naval Architecture and Marine Engineering at Glasgow University from 1893 to 1896. The first three of his gliders—the "Bat," the "Beetle," and the "Gull"—were built at Glasgow and experimented with on the banks of the Clyde at Wallacetown Farm, near Cardross. He later joined Sir Hiram Maxim at Eynsford, in Kent, where he built his fourth glider, the "Hawk." It was while making a glide on this machine on Saturday, September 30th, 1899, at Stanford Hall, Market Harborough, that the accident occurred which caused Pilcher's death on the following Monday. One of the gliders, which is the property of the Society, is now in the Royal Scottish Museum, Edinburgh, on permanent loan. Pilcher's private note-books of his experimental work constitute one of the most interesting items in the Society's library, where they are now lodged.

Journal.

In view of the necessity for cutting down all expenses to the minimum it is impossible to increase the number of copies of each issue of the Journal to be printed. At the same time, however, sales to persons outside the membership of the Society have been increasing, with the result that in a number of cases particular issues of the Journal become completely sold out within a few months of publication. Members who do not file their copies will greatly assist, therefore, if they would be so kind as to return any they do not wish to retain to the Secretary as soon as they have finished with them.

Chairman.

Two nominations from among the Members of Council have been received for the office of Chairman of the Society during the year 1921-1922. A ballot on these two names will be taken at the next Council meeting, on the 21st instant. The Chairman-elect assumes office on October 1st.

W. Lockwood Marsh, *Secretary.*

PROCEEDINGS.

NINTH MEETING, 56th SESSION.

The Ninth Meeting of the Fifty-sixth Session took place on Thursday, February 17th, in the Hall of the Royal Society of Arts, London, Sir JOSEPH PETAVEL occupying the chair.

The CHAIRMAN said the only duty he had, as Chairman, was the pleasant one of welcoming the Lecturer, Mr. Handley Page, and asking him to give an account of the extremely interesting set of discoveries forming the subject of the Paper. Mr. Handley Page was so well known in this country and the world at large that he needed no introduction.

Mr. F. HANDLEY PAGE then delivered the following Lecture :—

THE HANDLEY PAGE WING.

The present Paper is a record of experimental work carried out with a view to overcoming the phenomenon of " burbling." As is well known, the total pressure on an aerofoil is the sum of the positive pressure on the under side and the negative suction on the upper. If this negative suction can be made to increase progressively with increasing angle of incidence to angles greater than heretofore, the maximum value of the aerofoil lift coefficient will be increased. The effect of such an increase on aeroplane design depends upon the magnitude of the increase and the extra structure weight of the device necessary to obtain it. The present method which is now described has been evolved from experimental data, and an outline of the results is given below.

In a Paper which I read before the Royal Aeronautical Society in April, 1911 —ten years ago—I attempted an analysis of the somewhat meagre results then available on the pressures on plane and curved surfaces moving through the air. The effect now known as " burbling " was referred to as follows :—

> *" To obtain a law giving the normal pressure on a plane as a continuous function of the angle of incidence of the impinging air from 0 to 90 is impossible owing to the two distinct forms of flow that occur on the back of the plane. From the horizontal position of the plane up to an angle varying in magnitude from 10° to 50° depending on the aspect ratio, shape and curvature of the plane, the air hugs the back of the plane, the suction due to the rushing air is felt directly on the back of the plane, and the pressure increases continuously as some function of the angle. At angles greater than this critical value the air leaves the back of the plane, a ' dead ' air region is formed there, and any reduced pressure or suction on the plane back tending to increase the total ' lift ' is then solely due to the drag of the ' live ' air stream at the edges of this ' dead ' air region."

A further reference† was made later on in the Paper :—

> " The critical angle at which the ' live ' air leaves the plane back is reached earlier in the case of planes of high aspect ratio, and the latter accord-

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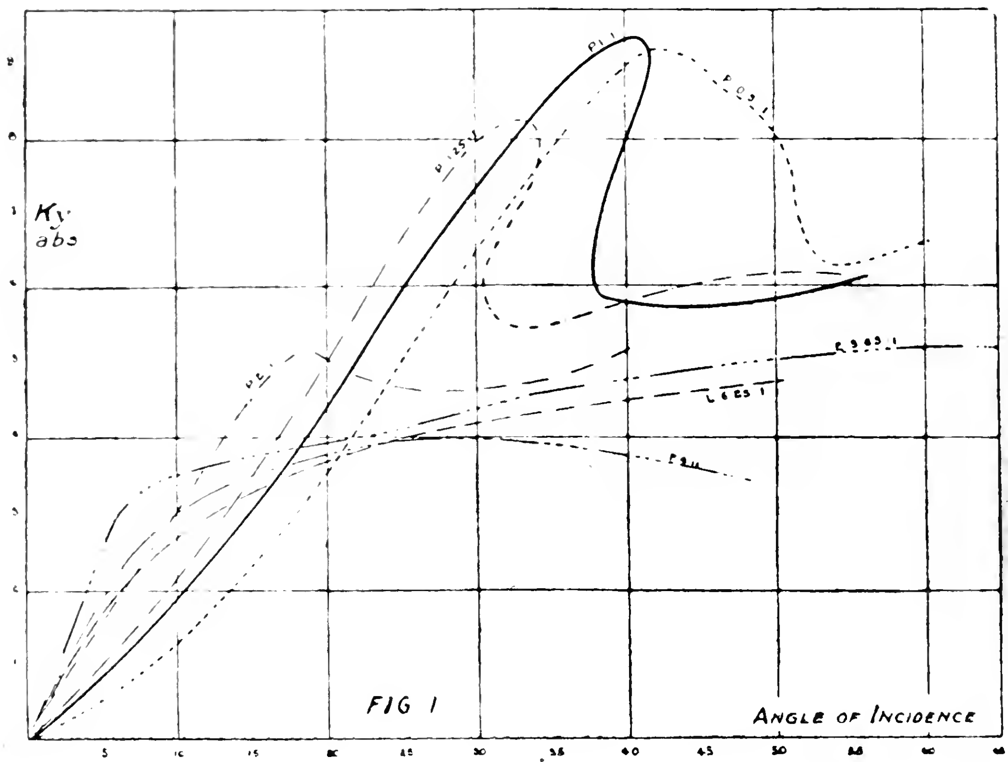
* " The Pressures on Plane and Curved Surfaces Moving Through the Air."—" Aeronautical Society of Great Britain Journal." April, 1911. Page 48.

† " The Pressures on Plane and Curved Surfaces Moving Through the Air."—" Aeronautical Society of Great Britain Journal." April, 1911. Pages 55 and 56.



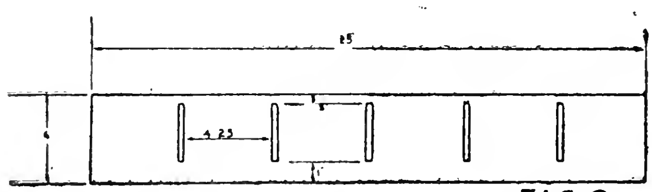
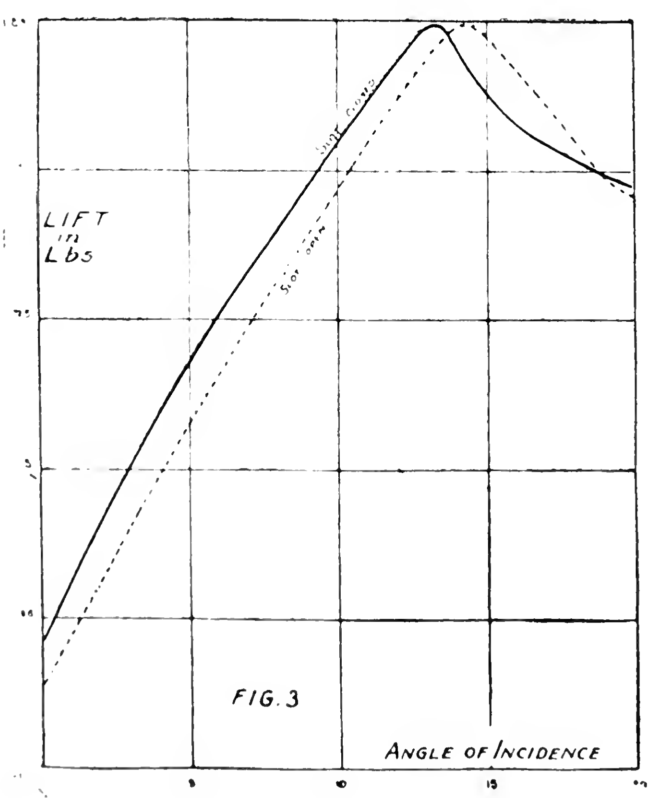


FIG.2.

H.P. aerofoil with five longitudinal slots.



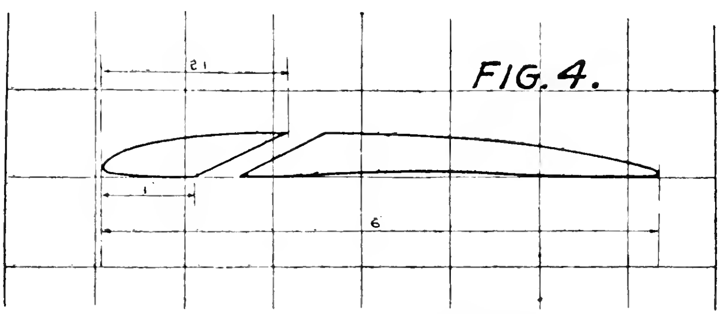
ingly do not have such high maximum values as the planes of lower aspect ratio.

"With planes of high aspect ratio there is not the same facility for the 'feeding in' of fresh air at the plane sides to act as a link between the plane and 'live stream,' and therefore the 'live stream' leaves the plane back at an earlier stage than in the case of the plane of lower aspect ratio."

In Fig. 1 is the set of curves reproduced from the 1911 Paper, showing the pressure on aerofoil as a function of the angle of incidence. It will be observed that the square aerofoil marked P. 1 : 1 continues lifting until 40°, whereas the aerofoil of aspect ratio 6.25 : 1 (marked L. 6.25 : 1) "burbles" between 10° and 15°. If, then, it were possible to convert the high aspect ratio aerofoil into a series of square ones and maintain the same conditions as in a square plane, higher maximum lift coefficients should be obtained.

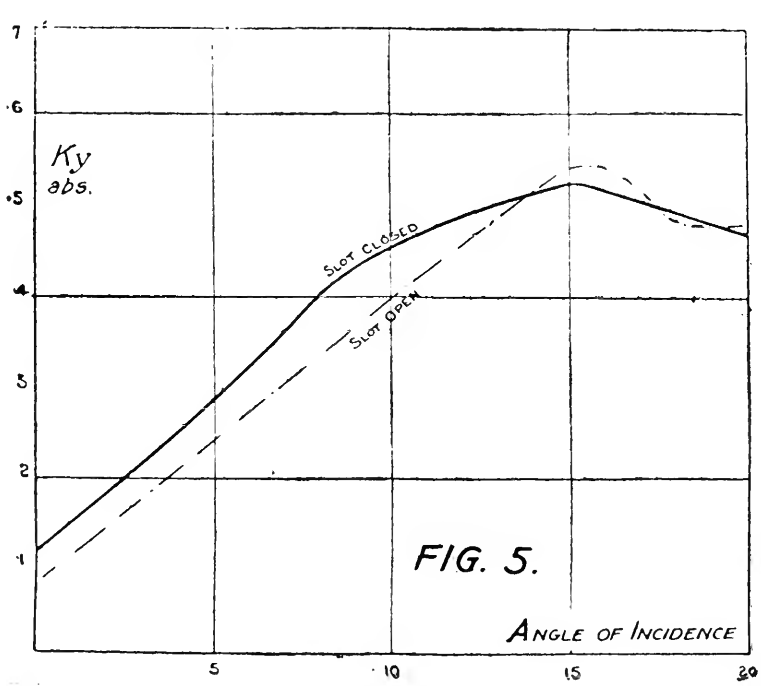
Fig. 2 is an aerofoil of aspect ratio $6\frac{1}{4}$ converted into six square planes by five slots, each parallel to the chord of the plane. With the slots open the total "lift" on the plane was slightly increased and the "burble" took place at 14° instead of 13° (see Fig. 3).

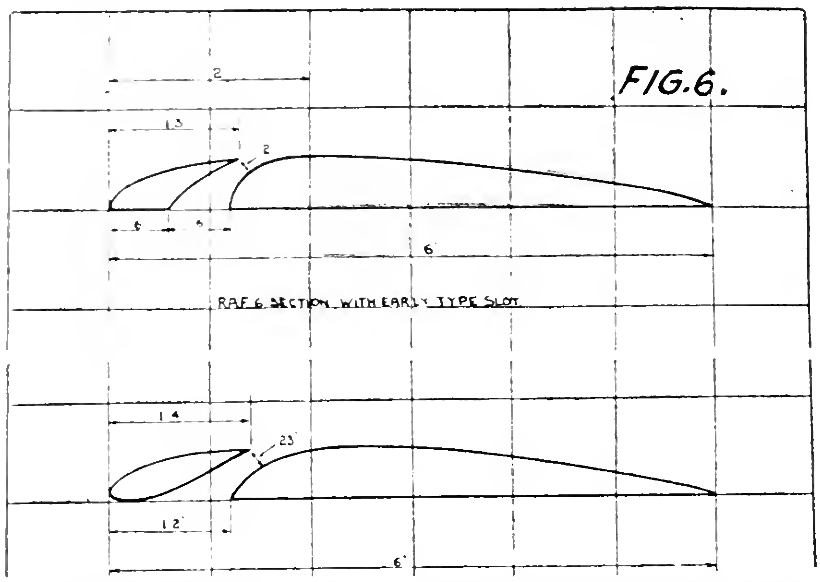
Improved results were later obtained with this form of slot, but this line of investigation was abandoned in favour of a transverse slot (see Fig. 4), which



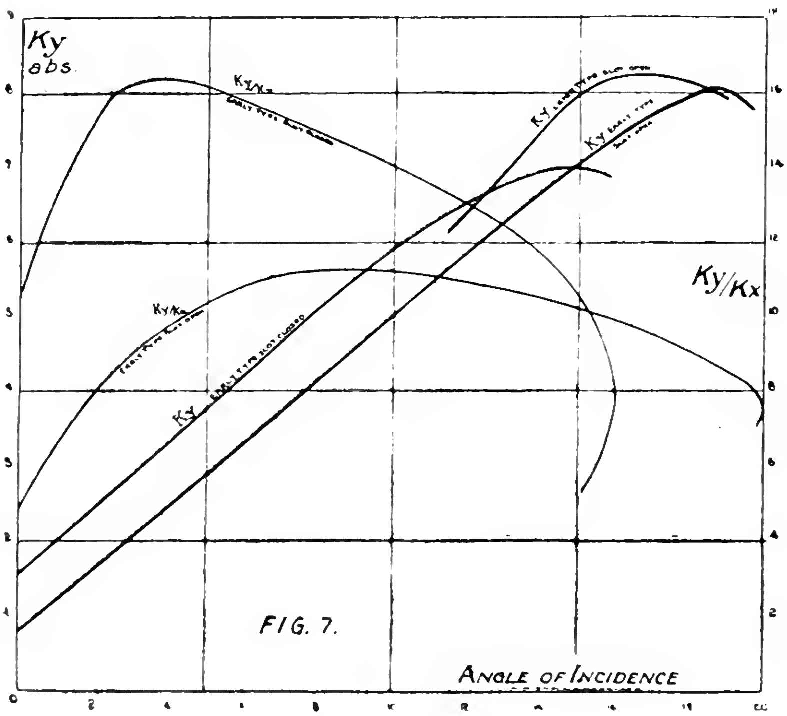
Plane section with early type slot.

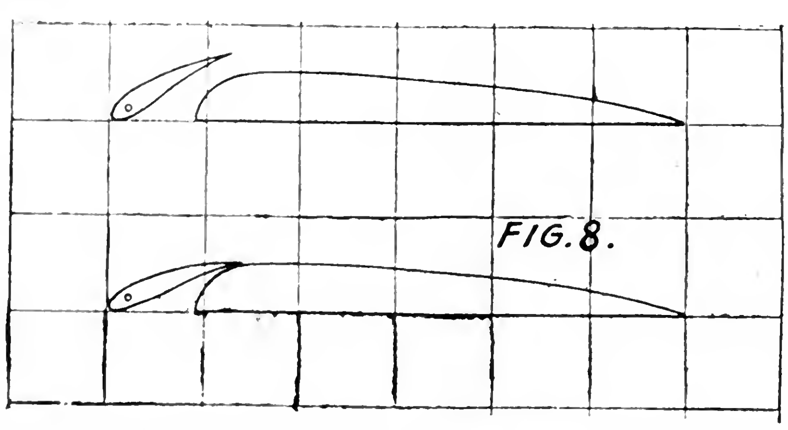
was tested on an aerofoil of R.A.F./15 section (see Fig. 5). The shape of the slot, the width of the two openings and the position of the forward small aerofoil and many other details, were found to have a very marked effect upon the resul





Top diagram shows R.A.F. 6 section with early type slot.
Lower diagram shows same section with later type slot.





Slotted aerofoil No. 32. Slot open and slot closed.

Fig. 6 shows some early type slots on a R.A.F./6 section, and Fig. 7 the results obtained. The lift coefficient increases about 25 per cent. with the slot opened. Further developments are shown in Fig. 8, where a simple single slot is formed by the swivelling front edge on aerofoil No. 32, which was approximately of R.A.F./6 cross section. This aerofoil was tested at the National Physical Laboratory at a speed of 80 feet per second, and the results are shown in Figs. 9 and 10. The maximum lift coefficient of the plane with the slot closed was .633 and with the slot open .943, an increase of 50 per cent. The maximum value of the lift/drag coefficient was 16.6 and 14.1 respectively.

These results have also been plotted in Fig. 10, on curves showing the relation between speed and horse-power per lb. weight, according to the method

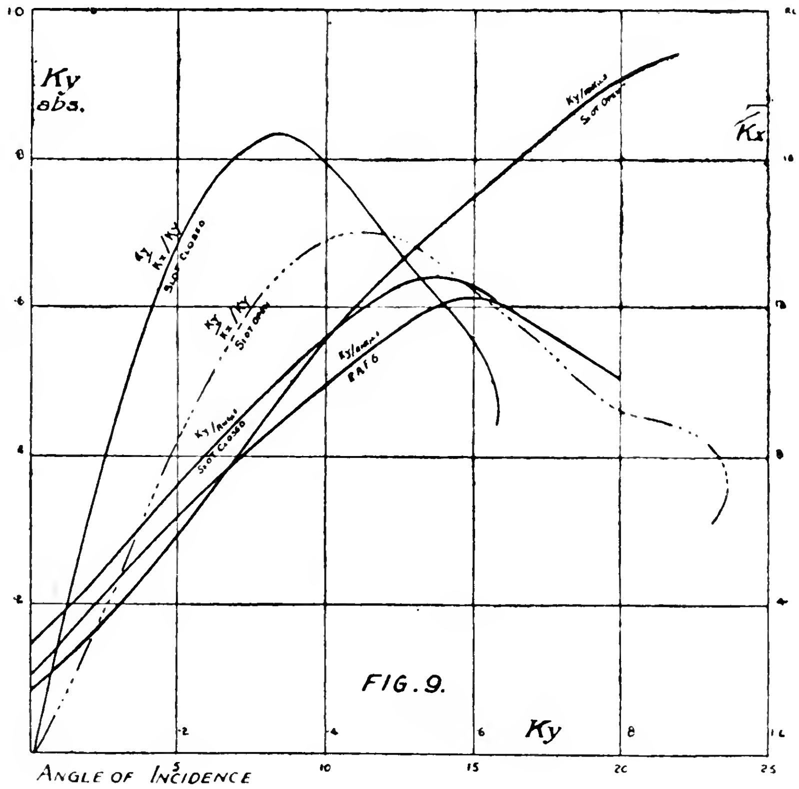


FIG. 9.

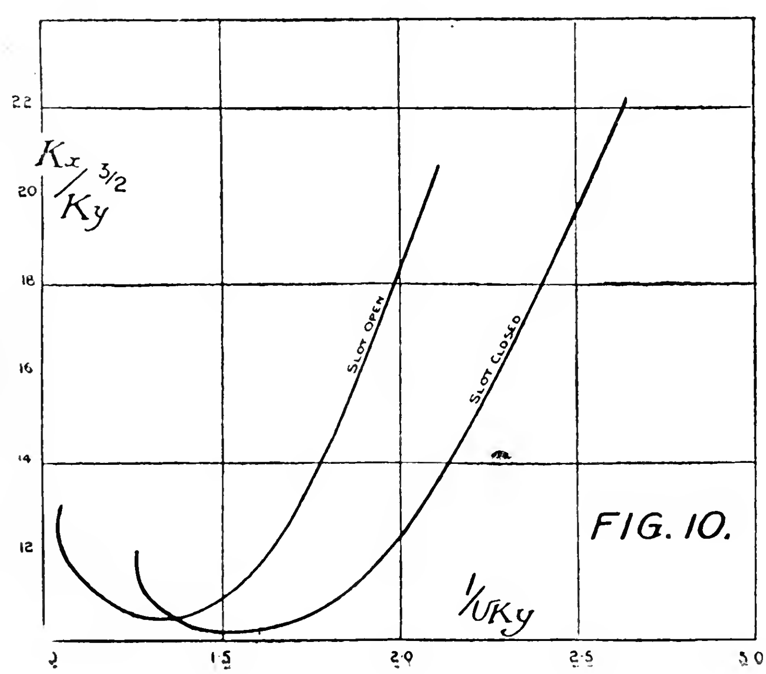
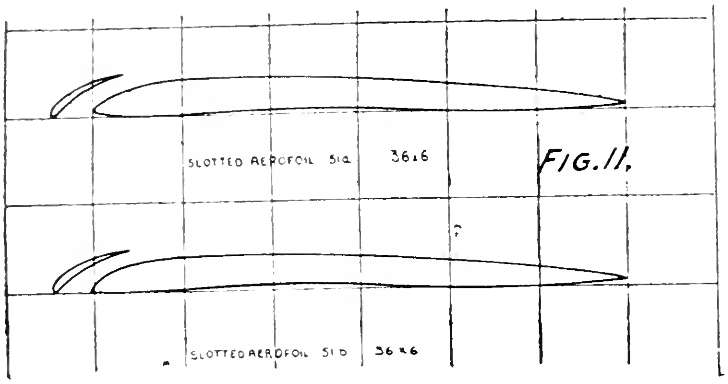


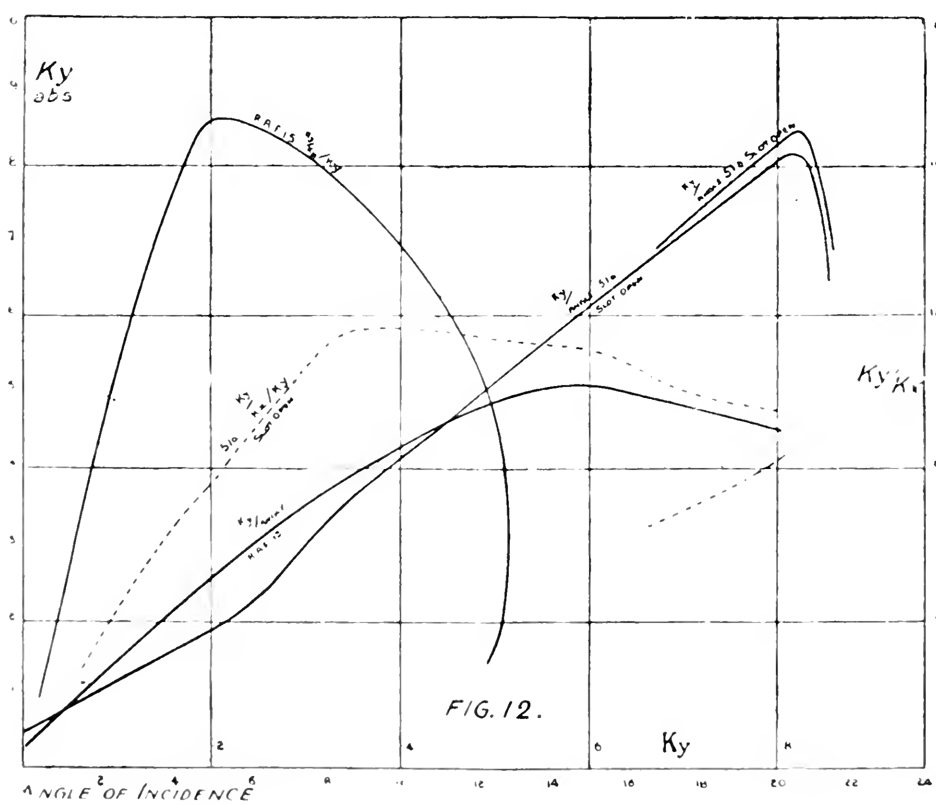
FIG. 10.

described in a Paper which I read before the Aeronautical Society in March, 1917. Speed is plotted as $\frac{1}{\sqrt{ky}}$, and horse-power per lb. weight as $\frac{kx}{ky\sqrt{ky}}$. With the slot open there is a reduction in landing speed of about 20 per cent., and with the slot closed practically all the advantages of the ordinary section.



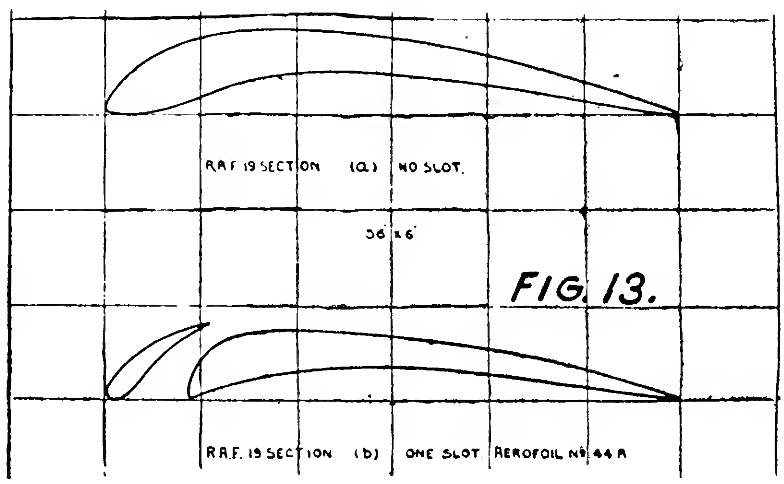
Above: Slotted aerofoil 51A, 36in. by 6in.
Below: Slotted aerofoil 51B, 36in. by 6in.

So far the tests described have been on one particular kind of section, and further experimental work has been carried out showing that similar results may be obtained with any type of section, both on what may be termed a "high speed" section, such as R.A.F./15, or a "high lift" section, such as R.A.F./19. Fig. 11 shows the R.A.F./15 section—51a and 51b—the section with the slot

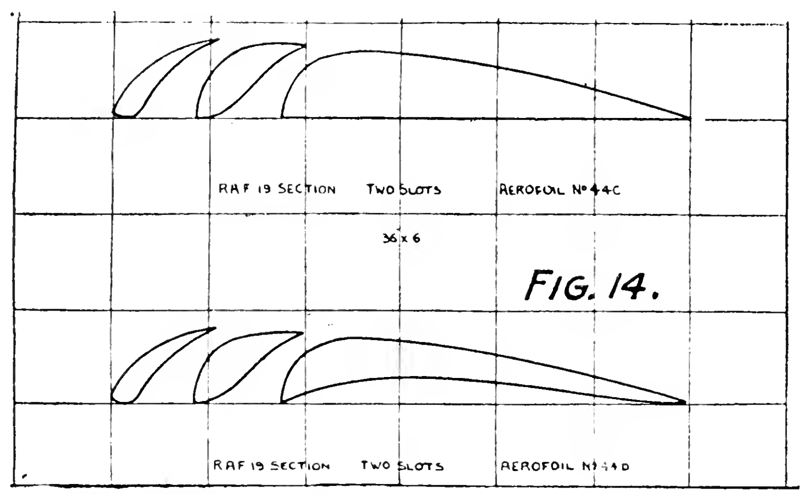


closed and the underside gap filled up being with a R.A.F./15. There is a slight difference between the two, 51a having the leading edge of the aft main aerofoil with a slight Phillips entry, whereas 51b has the leading edge of the aft aerofoil on the chord line. The results are plotted in Fig. 12, showing a slight improvement in lift in favour of 51b. A comparison between the R.A.F./15 and

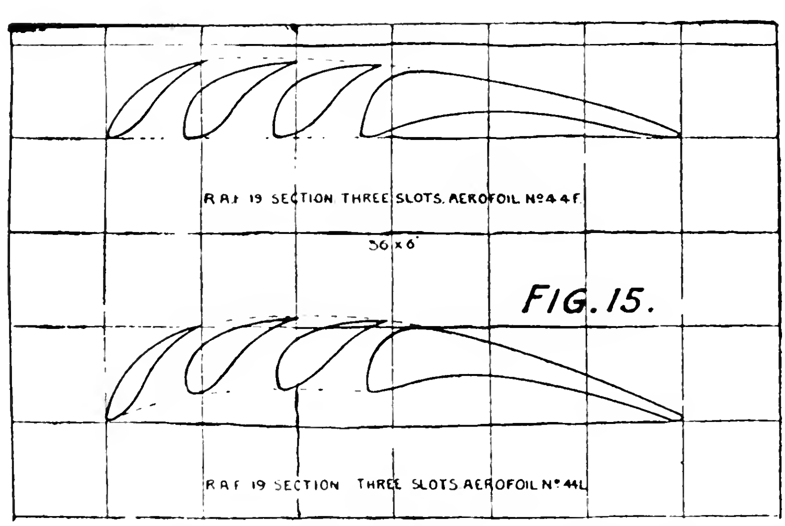
this section with the slots open is also given on the curves. The maximum lift coefficient is increased from .52 to .84, an increase of 61 per cent., and the lift/drag ratio is higher with the slot open at all angles above 12°.



R.A.F. 19 section. Above (a) no slot; below (b) one slot, aerofoil No. 44A, 36in. by 6in.



R.A.F. 19 section. Above: Two slots, aerofoil No. 44C; below, two slots, aerofoil No. 44D, both 36in. by 6in.



R.A.F. 19 section. Above: Three slots, aerofoil No. 44F; below, three slots, aerofoil No. 44L, both 36in. by 6in.

The same general type of results were obtained with a thick section, such as R.A.F./19, a section of which is shown in Fig. 13 with and without the slot, this aerofoil being No. 44. As, however, the R.A.F./19 is a section of small lift/drag ratio, the results of the single slot have not been included in this Paper.

An investigation of pressure distribution on the main and auxiliary aerofoils formed by the slot showed that the results obtained were of the same character

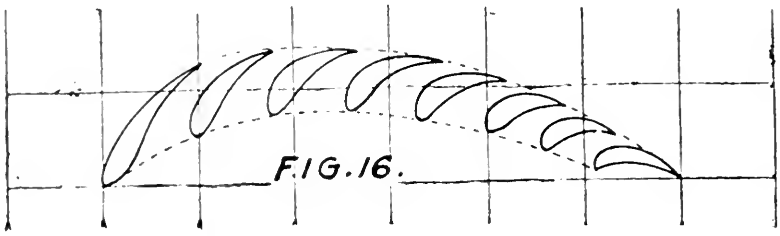


FIG. 16.

R.A.F. 19 section. Seven slots, aerofoil No. 53J, 36in. by 6in.

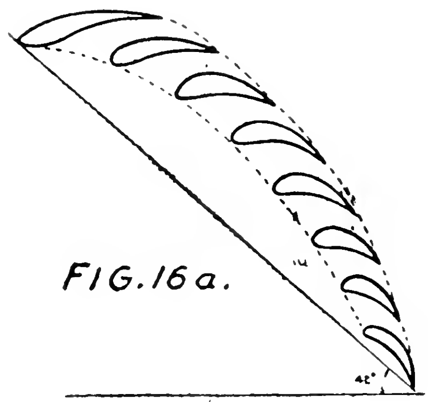


FIG. 16a.

RAF 19 7 SLOTS AEROFOIL 53 J

R.A.F. 19 section with seven slots; aerofoil No. 53J, 36in. by 6in. Section shown at angle of maximum lift.

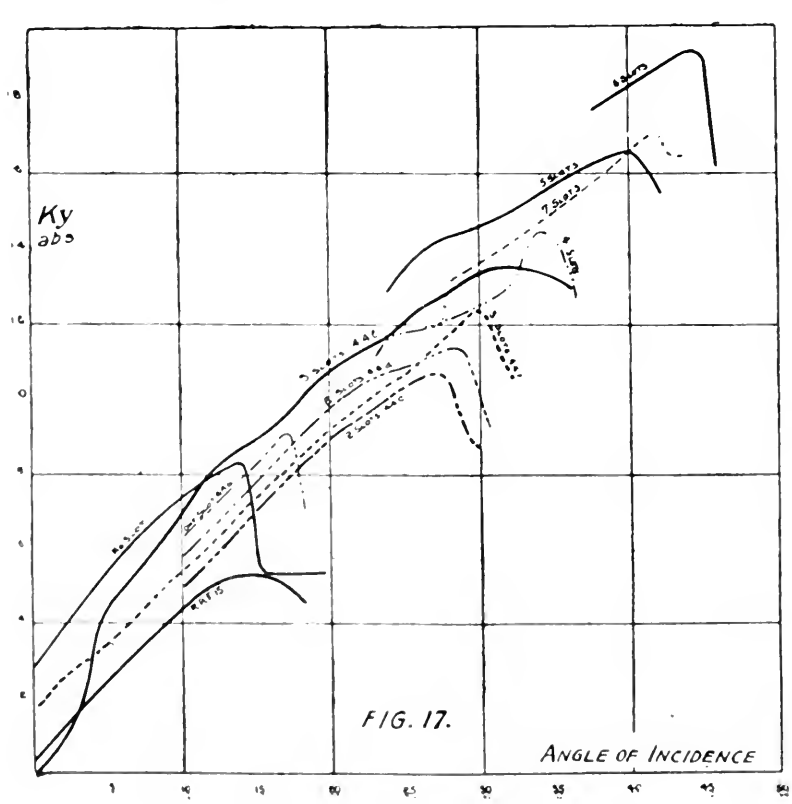


FIG. 17.

as in an ordinary aerofoil, and that "burbling" would take place on the small auxiliary aerofoil when it was at its critical angle, just as an ordinary aerofoil would do without a slot. It is evident that this can be overcome by further slots extending throughout the plane, and a series of experiments were accordingly carried out with various sections, to determine the lift that would be obtained with a multiplicity of slots. In Figs. 14, 15 and 16 the R.A.F./19 is shown with

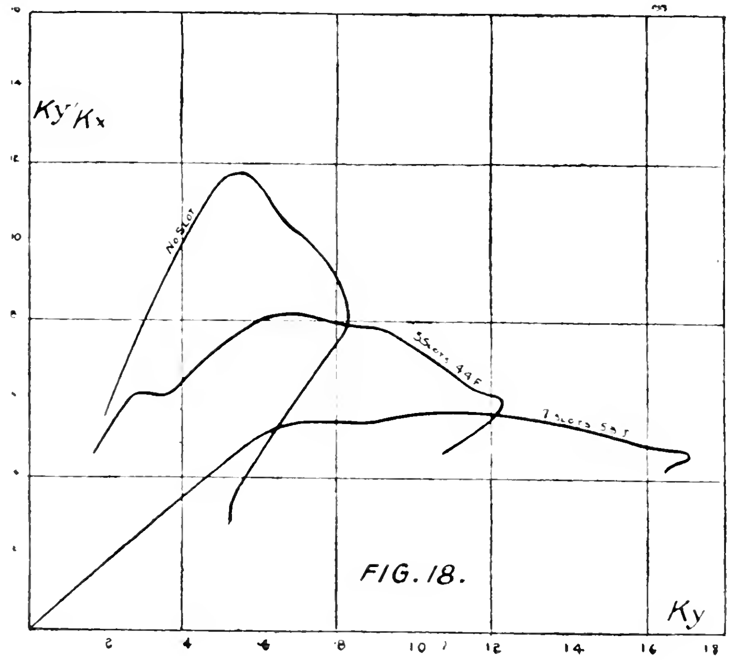


FIG. 18.

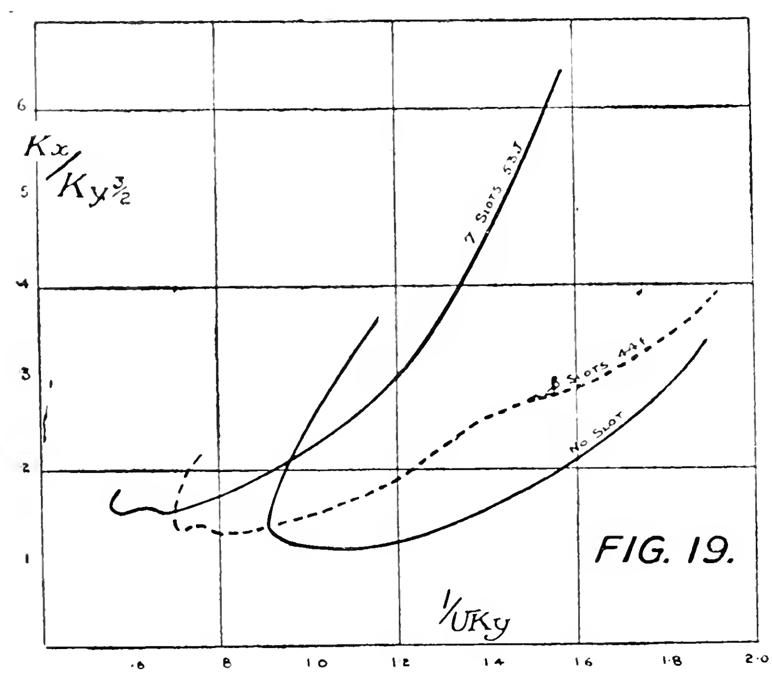


FIG. 19.

two, three and seven slots, and a series of experiments were conducted with each number of slots from one to seven. The results are plotted in Figs. 17, 18 and 19. With six slots the lift coefficient reaches the abnormal value of 1.96 at an angle of 45°, and in comparison the curve of R.A.F./15, which is also plotted on Fig. 17, looks almost microscopic. At the angle of inclination of 45° at which this large value of lift coefficient is obtained, the tangent of the trailing edge of the aerofoil is practically vertical, showing that the air is being deflected through the maximum angle possible and is leaving the plane practically in a vertical direction. Fig. 18 shows the lift/drag plotted against lift coefficient, and Fig. 19 the horse-power per lb. weight against speed.

These tests indicate that with a multiple-slot arrangement an increase in lift coefficient can be obtained of two to three times the normal value without the slot.

The tests so far described have all been monoplane tests, carried out in the wind tunnel at a speed of 40ft. per second. A further series of tests was carried out on several sections—of which aerofoil 42 is an example—to determine

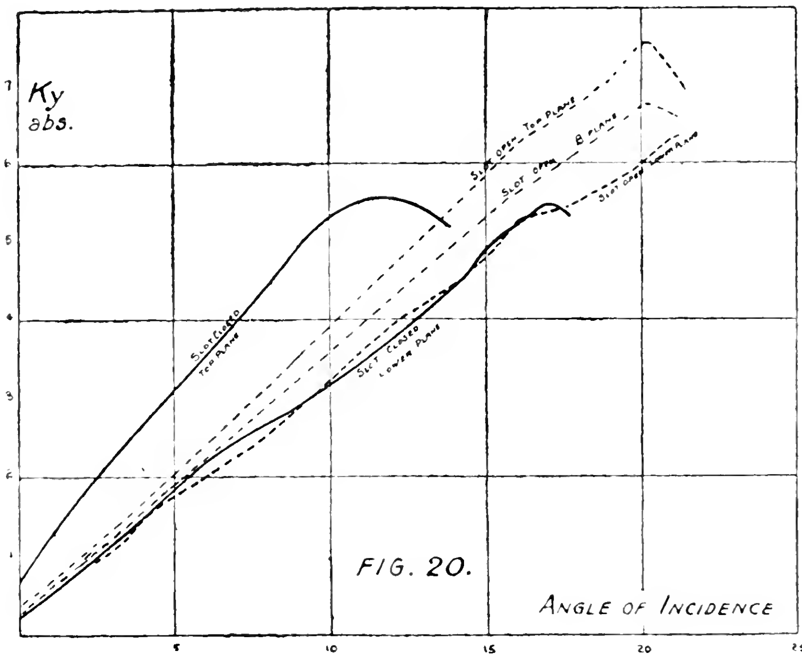


FIG. 20.

whether the same effect could be obtained on a biplane. The results in Fig. 20 indicate that an increase in the lift coefficient of approximately 40 per cent. was obtained with a single slot, and that a normal result was obtained. Further tests carried out since have clearly shown that with the necessary biplane corrections the slotted monoplane tests can be applied to biplane calculations.

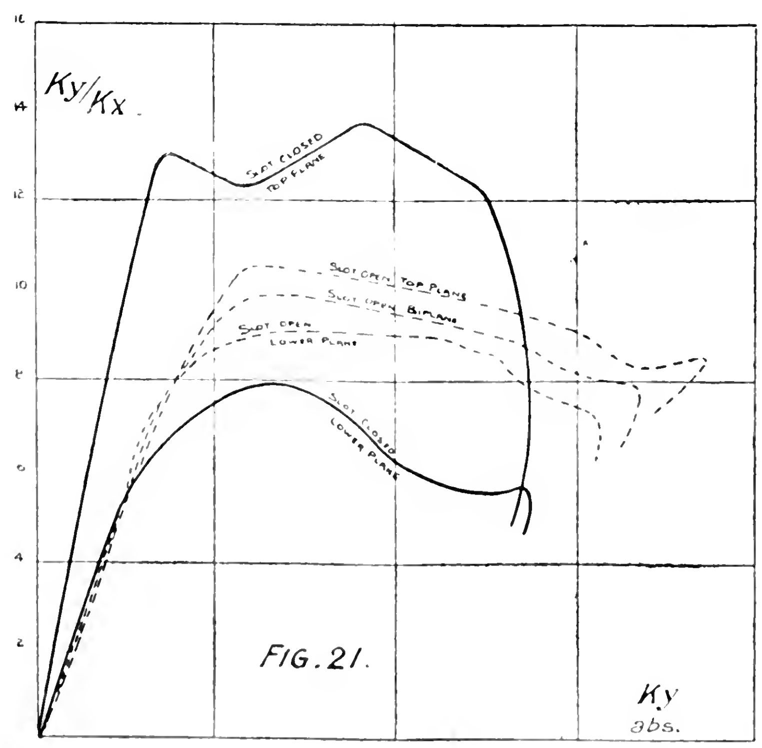


FIG. 21.

Centre of Pressure Tests.

Aerofoil No. 32, the lift/drag coefficients for which have already been plotted in Figs. 9 and 10, was tested for its centre of pressure movement, and the results are plotted in Fig. 23. At any given angle the centre of pressure with the slot

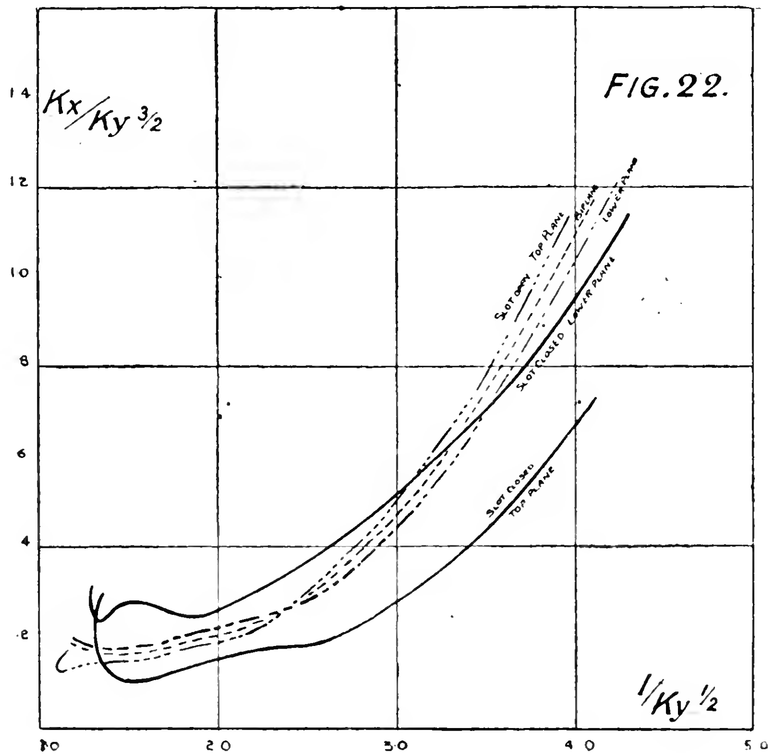


FIG. 22.

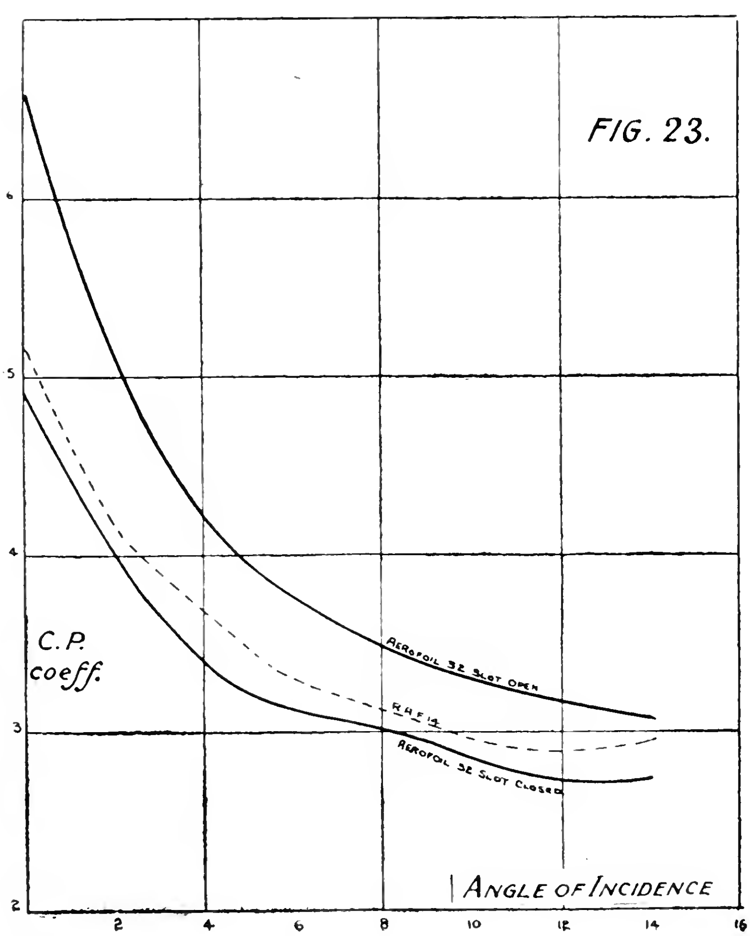


FIG. 23.

open is slightly farther back, but taking into account the decrease in lift co-efficient at small angles with the slot open, for any given value of the lift co-efficient the difference is not great. The general result, however, of the centre of pressure line being slightly behind that of the normal position is one that might be anticipated, as the pressure is more evenly distributed over the whole plane, and therefore the aft portion has a greater lift. This causes the result of the centre of pressure to lie farther back.

In commenting on the tests carried out on this section, the National Physical Laboratory reported as follows:—

> "The high lift obtainable with the flap open is very remarkable, especially in view of the fact that the position of the centre of pressure is little altered. At the critical angle the C.P. is at 0.295 chord with flap open, which corresponds with its position at about 8° incidence with flap closed. The longitudinal balance of the machine would be approximately the same when flying at 8° incidence or landing at 22° incidence, a very valuable characteristic. Scale effect in lift and drag are both considerable, but little effect on C.P. is found."

Flap Experiments with Slotted Aerofoil.

An increase in the lift coefficient can be obtained by the use of a plane with flaps and altering the angle of incidence of these flaps. A series of tests were carried out at the National Physical Laboratory, published in the Report for the year 1913-14, pages 111 to 128. The results have been plotted in Fig. 24, com-

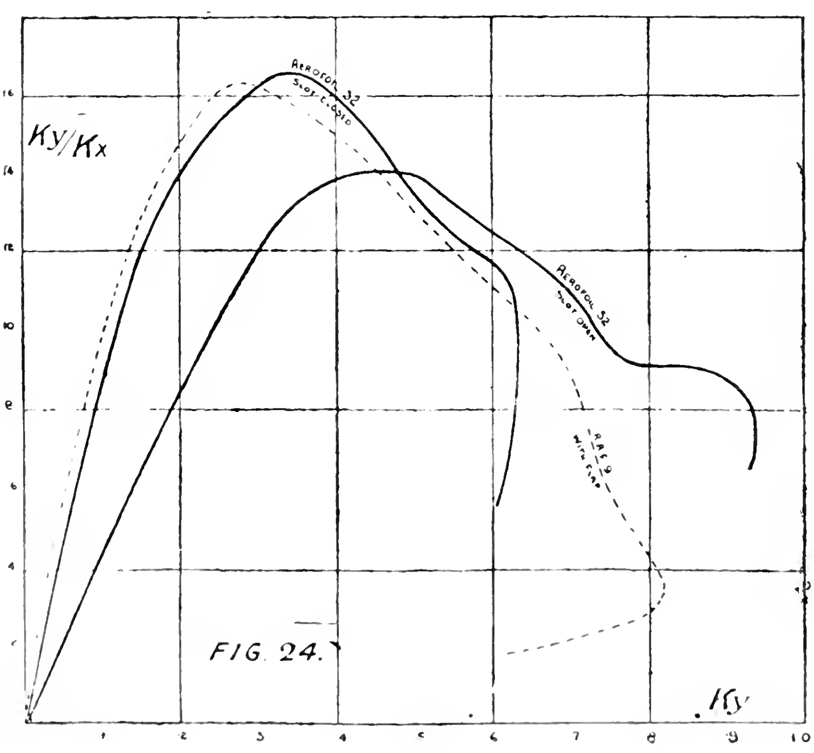
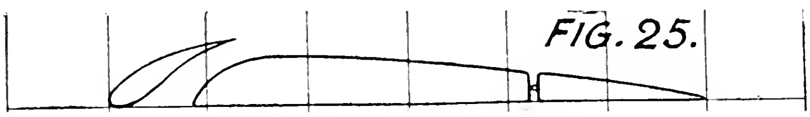


FIG. 24.

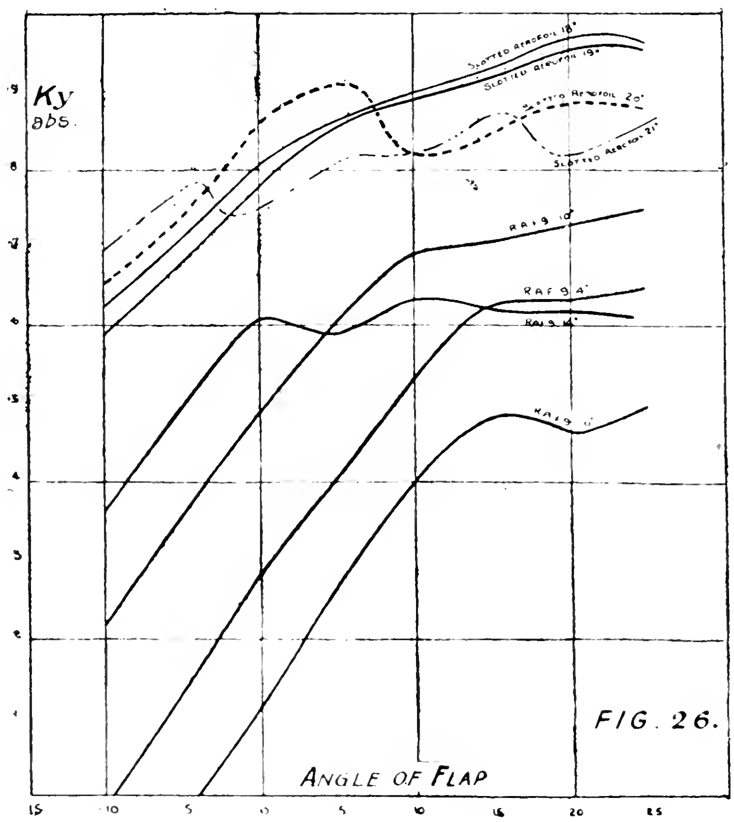
pared with aerofoil No. 32 with the slot open and the slot closed. The R.A.F./19 curve shown is the envelope of the various curves, as plotted in Fig. 32 of the Report referred to above. The maximum lift coefficient on aerofoil No. 32 is approximately .943, as against .82 with the flap, which at this value was set back at an angle of 60°.

The increase in lift coefficient by the use of flaps can be obtained with the slotted plane as with the ordinary one.

A series of tests were carried out on the section shown in Fig. 25, and the results are plotted in Fig. 26. With the plane inclined at 18° and 19°, a progressive increase in the lift coefficient is obtained, but at 20° and 21° the plane is inclined at the critical burbling angle, and owing to this results are somewhat



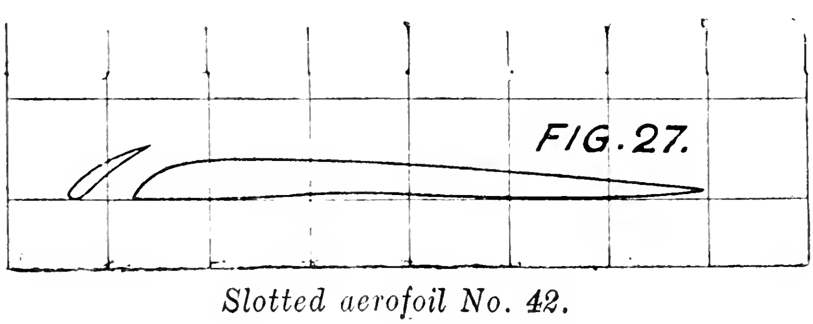
Slotted aerofoil with flap.



unstable. Further experiments have determined that the rolling moments obtained with the alteration of the flap angle are of the same order as those on the plane of ordinary cross section, indicating that full control can be obtained by ailerons in the ordinary manner when the slots are open.

Pressure Plotting.

Reference has already been made to pressure distribution plotting on a slotted plane. These experiments were carried out on aerofoil No. 42, this being a



Slotted aerofoil No. 42.

R.A.F./15 section with an extra nosepiece added—Fig. 27. The results are shown in Fig. 28. The shape of these curves is very similar to that of the ordinary pressure plotting, except for the break in the curves where the slot is opened and the higher values in pressure obtained at the leading edge of the aft plane.

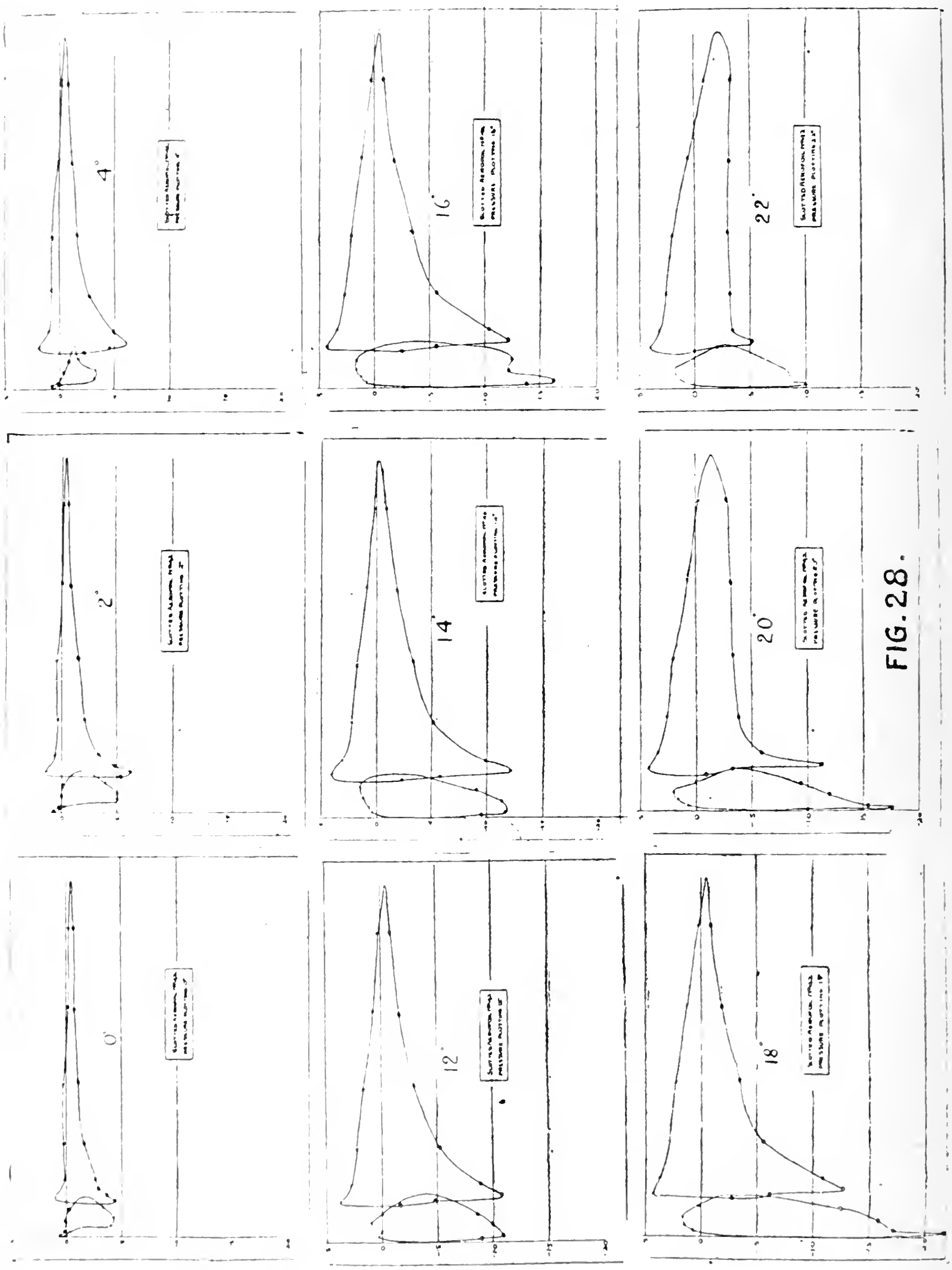


FIG. 28.

General Conclusions.

The record which has been given is one of progress in experimental work with the slotted plane. In general, the results show that depending upon the slot shape, position, width, inclination, etc., an increase in lift coefficient of from 40 to 60 per cent. can be obtained with one slot, and up to 200 to 300 per cent. with a multiplicity of slots. The drag coefficient is slightly increased on the slotted

plane with the slot closed, compared with an unslotted plane of similar cross section. The gap on the lower surface of the plane makes but little difference to the drag, but any discontinuity on the upper surface is at once attended by a large increase in the drag coefficient. With flaps fitted to such an aerofoil the necessary increases in lift coefficient can be obtained, so that a proper aileron control is still available. This is a distinct advantage over the method of increasing the lift coefficient by alteration of the flap angle, for with the flap at its maximum angle no aileron control is possible.

The centre of pressure is slightly aft of the position at smaller angles on a plane of similar section, but unslotted. This result is evident from an examination of the pressure slottings which show that distribution of pressure on each of the smaller constituent aerofoils, whilst similar to an ordinary aerofoil, result in the lift being more evenly distributed over the plane.

Causes of "Burbling."

If reference is made once more to Fig. 28, it will be seen that as the angle of incidence is increased, the pressure at the leading edge increases very rapidly. At 14° the negative suction on the upper surfaces of the plane reaches a value of 1.2 for both auxiliary and main aerofoils. After this point is reached, the auxiliary aerofoil's pressure increases more rapidly, reaching 1.65 at 16° and 2.2 at 18°. At 18° the abnormal pressure increase over the small area at the front edge of the auxiliary aerofoil is followed by a very rapid pressure drop, the pressure on the main aerofoil only reaching a value of 1.3. This very steep pressure graduation immediately results in "burbling," the maximum value of the pressure at 20° having fallen to 1.75.

The same type of results are found with an ordinary plane, except that the rapid rise in pressure of the leading edge would have taken place at a smaller angle. To prevent "burbling" it is therefore necessary to ensure that the angle of the auxiliary planes is always kept sufficiently small, so that a rapid increase in pressure is avoided.

With a multiplicity of slots this is possible, as has already been shown in the case of the R.A.F./19 tests. It would appear that the rapid rise in pressure is due to an abnormal velocity increase, with corresponding contraction of the live air stream, and that slightly farther back on the plane the necessary velocity reduction cannot be effected without setting up discontinuity and the eddying effect known as "burbling."

Effect on Design.

The increase in lift coefficient possible with the slotted aerofoil permits either of slower running speeds than at present or, alternatively, of less power at top speed. The first is self-evident; the second requires some explanation.

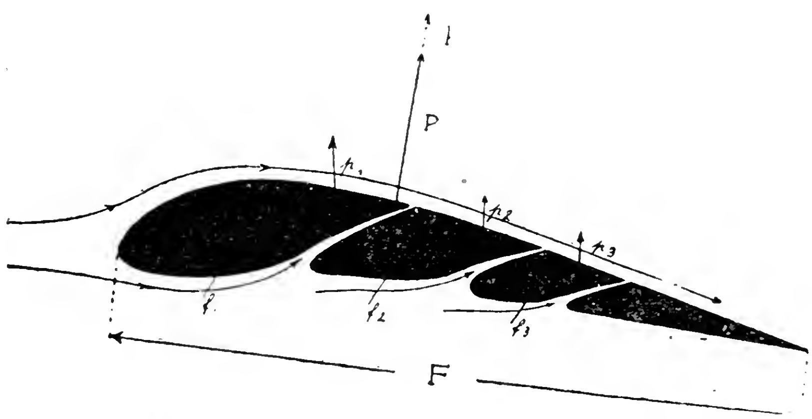
In an aerofoil design with unslotted planes, the lift coefficient at top speed is usually less than that at which the best value of lift/drag is obtained. The landing speed and maximum lift coefficient determine the value of the lift coefficient at full speed, the drag at this latter speed—excluding body resistance for the moment—the horse-power required to obtain this speed.

With the slotted plane the reverse procedure may be adopted. The lift coefficient top speed can be chosen with reference to the best lift/drag ratio of the plane, and the slow speed for alighting obtained by the provision of the necessary number of slots to give the required lift coefficient. At top speed it will therefore now be possible to work at lift coefficients between .2 and .3 instead of the lower values which call for the use of a section such as R.A.F./15 with low values of drag at very small angles. The trend of design would therefore be towards the choice of sections with high lift/drag ratio rather than fairly high lift/drag ratios at low values of the lift coefficient.

If, then, machines can be designed with their planes at normal cruising speed, set at angles of incidence where the lift/drag ratio is not less than 16 and perhaps as high as 21 or 22, a great economy will be effected in the horse-power that is required. Economy does not, however, rest with the planes alone, for if the planes are more efficient it will pay to sacrifice a little weight to diminish the body resistances of the aeroplane.

It would appear from our recent experiments that a total lift/drag ratio on a complete aeroplane can be obtained of not less than 1 to 15 at the top speed. With this value and a propeller efficiency of 70 per cent., a speed of 120 miles per hour can be obtained with 33lbs. per horse-power. It is evident that results such as these will emphasise the importance of improved methods of propulsion at slow speeds, so that the problem of arising with such heavy loads per horse-power is made easier than it would be at the present time.

The experimental results which have been given above have been confirmed by full size tests on a D.H.9, the front edge of which was altered so that its section included a slot in front of the front spar. The increase in lift coefficient measured from the decrease in stalling speed showed that the full scale results followed closely the laboratory experiments.



The German Lachmann Wing: A model of this was tested in the Handley Page wind tunnel, but gave a maximum lift coefficient of 0·5 (absolute) only.

Mechanical Devices Necessary.

The operation of the auxiliary plane or planes to effect the transformation from slot closed to slot open does not present very great difficulties, nor does their addition to the structure lead to very much increase in weight. One of the simplest methods is by the simple swivelling of the front auxiliary portion, but in this device and in the actual methods of control, many solutions are possible, and experience in manufacture and operation can only indicate which is the best. It is to be hoped that the results which have been given above and the investigation which has been conducted will lead to further experiments being carried on elsewhere, so that improved results may be obtained to the benefit of aircraft and aviation generally.

The writer's thanks are due to Mr. R. O. Boswall, now lecturer on mechanical engineering at Manchester University, and who, until the beginning of last year, was in charge of our wind tunnel and carried through all the original experiments, as well as to his successor, Captain G. T. R. Hill, and Miss Chandler and Messrs. Reynolds, Pirrie, Hall, Miles, Campbell and Fossett, assistants in our Research Department, for their able assistance.

DISCUSSION.

The CHAIRMAN said he had before him a remarkable collection of experts in the various branches of this subject. This new departure in wing design would, he thought, undoubtedly produce important results, and it would be interesting to call first upon one of the pioneers of the aeronautical world, by asking Colonel Ogilvie to give his views, as he had watched the development of wings from quite an early stage to the latest one.

Colonel OGILVIE: In the first place I should like to compliment Mr. Handley Page on the way in which he has presented to us the results of this research work, and to congratulate him on his remarkable discovery.

It is difficult to discuss details of the Paper without close study of the curves and diagrams, but if the general conclusions are correct it is evident that the possibilities are very great.

The simplest thing to do is to compare a machine capable of carrying 33lbs. per h.p. with a machine of the present day, which to do 120 miles an hour cannot be loaded at much more than 12 to 15lbs. per h.p. A very simple calculation shows that in a 33lb. per h.p. machine, the weight per h.p. available for load is at least three times as great as for the 15lbs. machine. Fuel costs, which form so large a part of the total costs in civil aviation, will only be a third.

Lower landing speeds will greatly increase safety and will lower insurance rates. This question of lower landing speeds is in my opinion a very important point and it is to be hoped that the benefits to be obtained from this discovery will be applied to this requirement of increasing safety to the fullest extent possible.

The present speeds of 120 m.p.h. are adequate to deal with adverse winds, but the landing speeds of 60 m.p.h. or thereabouts are altogether too high for safety, particularly when they are combined with fine gliding angles.

What other effects on design may we expect? The point which strikes me most forcibly is that the weight available for the engine, its accessories, gears and propellers will be more, and that it will pay to use gears and propellers of variable pitch. Mr. Handley Page draws attention to this point in his Paper, and it may interest him to know that in my own machines, which were Wrights with certain alterations, the weight lifted was 33lbs. per h.p. with a surface loading of about $3\frac{1}{2}$lbs. per sq. ft., and that the power plant with its propellers, shafts and gears weighed about 11lbs. per h.p. My speed range was 36 to 50 miles per hour. Present engines weigh about 3lbs. per h.p. complete, and it will be worth while in view of the other advantages of stability and controllability to set aside another two or three lbs. per h.p. for gears.

We may also expect to see undercarriages having considerably greater shock-absorbing qualities whose resistance will be diminished by being wholly or in part withdrawn into the body, which we may expect to be larger but of better shape.

On the other side the difficulties of altering the angle of incidence of the wings through 40 degrees as well as altering their individual shape appear to be considerable and the more designers who tackle the problems the better.

Even if the full benefits of this discovery do not become available for some time, it is clear that a very great aerodynamic advance has been made.

In a recent paper, Colonel Tizard said that the worst feature of civil aviation of the present day is that it does not pay, and the best feature that it very nearly pays.

Let us hope that this piece of research work will enable civil aviation to step out of one class into the other.

Professor L. Bairstow said it was clear that Mr. Handley Page had made a lot of unsuccessful experiments on getting rid of eddies before he got on the right track. Had he only given the final result instead of a history of the experiment many of us would not have received a correct impression of the amount of work involved in establishing a new fact. As it is, after considerable expenditure of effort, the Lecturer suggested that further experiments were necessary. On the main points of the advantages of the new wing he agreed with the last speaker, and also with the Lecturer in his summing up, more especially in regard to the reduction of landing speed which could be secured. It was not quite so easy to get the full advantage of a high-lift wing in the improvement of top speed, but Mr. Handley Page's figure of 15 as the possible lift drag ratio was a great improvement on the present day 9. The centre of pressure problem in the variable-cambered wing—or the new Handley Page wing—was not the same as in a fixed wing. Balance in machines depended on the position of the centre of pressure on the main planes and also on the down-wash; the latter was affected by the opening or closing of the slot, but in all cases the angle of down-wash was roughly proportional to the lift coefficient. If an aeroplane—flying just above the stalling speed with the slot closed—had the slot opened, there would be an increase of lift coefficient, a correspondingly increasing down-wash, and a depression of the tail. What one would like was that the centre of pressure should have a tendency to go back to correct for down-wash. It was conceivable that by changing the wing section in the middle of the plane—the part which produces down-wash over the tail—an exact correction between the centre of pressure changes and the lift coefficient changes from the closing of the slot could be obtained, but that point would need a considerable amount of further study. With regard to lateral control, Mr. Handley Page had shown that flaps would operate behind a wing which had a slot, but the curves also showed that a slotted wing was more liable to spin than a wing of normal character. On the other hand, it did not spin until stalled, and the stalling angle occurred much later. If a wing of that description did stall the rate of rotation in the spin would be much greater than in the case of more usual wing forms. The problem of preventing that spin was accentuated with a high-lift wing, and we were not yet fully prepared to deal with methods for eliminating spin in existing aircraft, although indications had been obtained as to the possibility.

Captain W. H. Sayers said it was curious how many people had tried to anticipate Mr. Handley Page and had failed. In 1910 Mr. Molesworth and Mr. Hughes produced a triplane—a heavily staggered multiplane. The only information to be got out of Mr. Molesworth was that his front plane was set at a less angle of incidence than his succeeding ones, and that it acted as a guide plane to deflect the air downwards in gradual steps instead of at one jump. He had his leading wing under the one behind it, *i.e.,* the wrong way up, and that particular wing never worked, as far as he knew. He (Mr. Sayers) had tried to impress high-lift wings on the world for a number of years, with little success. Mr. Handley Page seemed to be doing better. He was fortunate in having a high-lift wing which he could turn into a high-speed wing. If he found the mechanical difficulties of converting his very high-lift wing into a reasonably high-lift/drag ratio wing too great, he could still do a fair amount—say with the range between a lift coefficient of 2 and a section which was as bad as R.A.F.19. His speed came down to 90 m.p.h. for a landing speed of 45, and with that he should be able to carry 42lbs. per h.p. and lift of 20lbs. per sq. ft. This should be comparable with 22lbs. useful load per h.p. with four hours' fuel. The fuel expenditure would not be higher than with the present-day machines and the running cost per h.p. should be the same. The average man said 10 guineas for flying to Paris in $2\frac{1}{2}$ hours was too high, but if it were put at three and a half guineas for $3\frac{1}{2}$ hours' trip he might consider the matter more favourably.

Dr. A. P. Thurston thought it would be agreed that aeroplanes had reached,

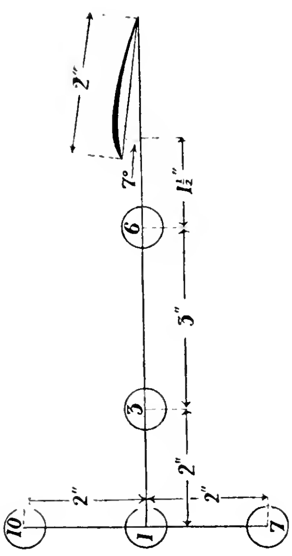


FIG. 1.

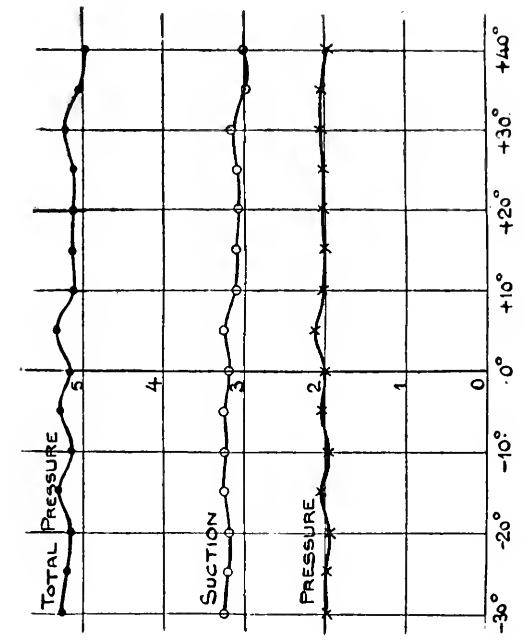


FIG. 3.

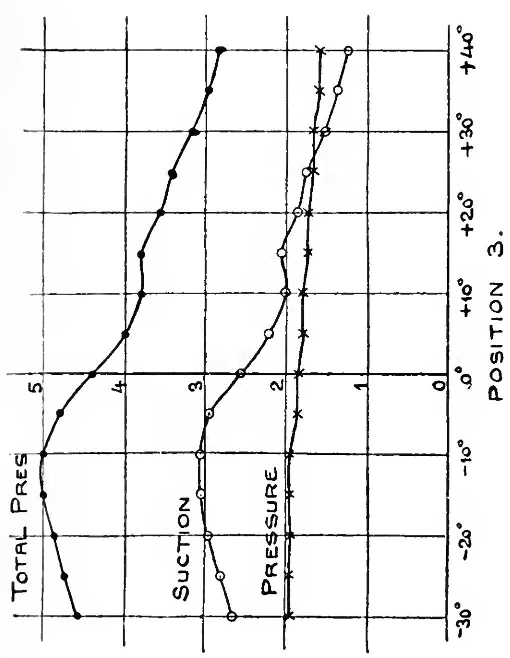


FIG. 6.

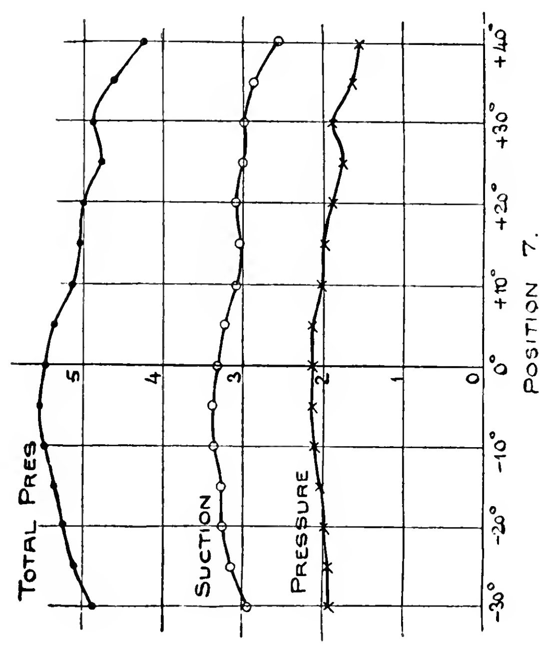


FIG. 4.

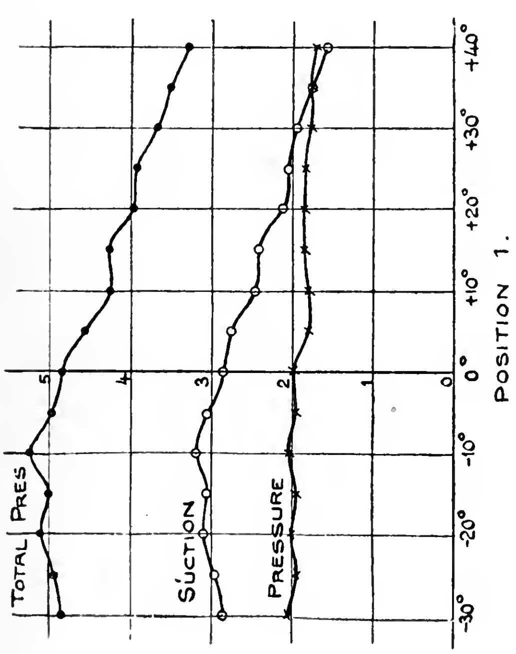


FIG. 5.

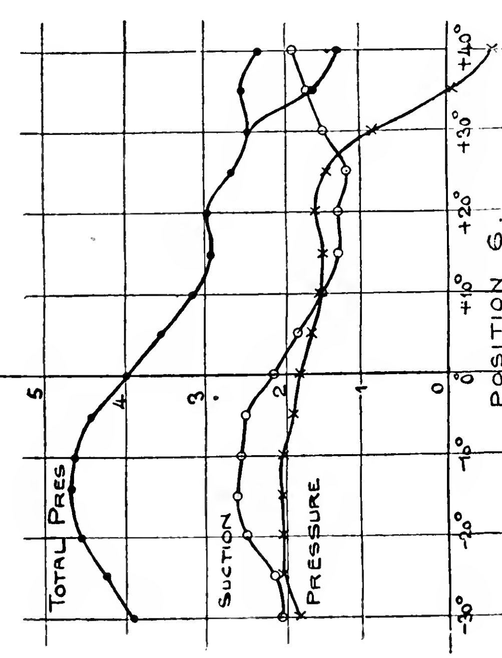


FIG. 7.

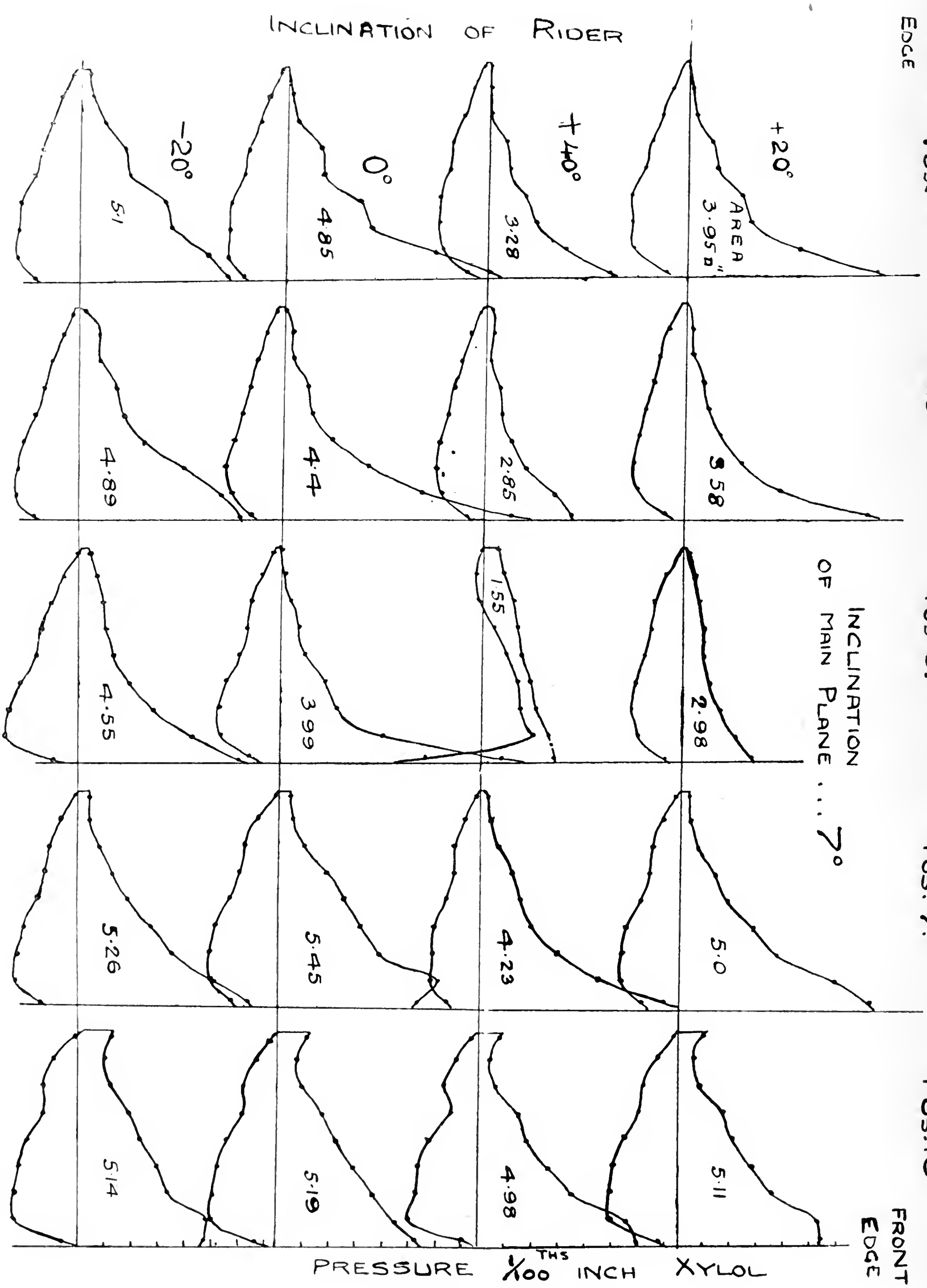

Inclination of Rider
Rear Edge
-20°
0°
+20°
Pos. 1
Pos. 3.
Pos 6.
Pos. 7.
Pos. 10
5.1
4.85
3.28
Area 3.95□"
4.89
4.4
2.85
3.58
4.55
3.99
1.55
2.98
Inclination of Main Plane ... 7°
5.26
5.45
4.23
5.0
5.14
5.19
4.98
5.11
Front Edge
Pressure 1/100ths inch Xylol

Fig. 2.

more or less, the limit of their development, unless some revolutionary system of support or a completely new form of prime mover was evolved. There seemed no immediate probability, though there was a possibility, of a new prime mover. Mr. Handley Page was to be congratulated on bringing before them one aspect of a new system of support which seems to promise a future.

The invention or discovery was worked out to some considerable extent before the war. Reference was made to the experiments of H. P. Molesworth and the Molesworth-Hughes multiplane embodying these principles described in the AERONAUTICAL JOURNAL of April, 1911. Quite independently, at East London College, he had worked out, more or less, the whole of the theory, before the war. He would show some diagrams from one lecture of a series given before a large audience at East London College on June 10, 1914, which might clear up some points left in doubt by the lecturer. The first diagram, Fig. 1, showed the position of the main plane relative to a small rider plane. These could both be rotated together through any angle, and, in addition, the rider plane could be moved to any position vertically or horizontally and be rotated to any angle in any of those positions, illustrated, for example, by positions 1, 3, 6, 7, and 10. Many other positions of the rider were experimented with. He showed a number of pressure diagrams as the rear plane or the little rider plane were rotated. The next slide, Fig. 2, gave pressure diagrams for the rear plane at a fixed angle of 7 degrees with various positions and angles of the rider, *i.e.*, with various widths of gap. In position 10, Fig. 3, there was very little alteration in the total pressure or lift on the main plane, whatever the inclination of the rider, from plus 40 degrees to minus 40 degrees. At least three years elapsed between taking the first and last readings of these diagrams, which were very numerous. The slight changes in total lift of the rear plane are not much greater than would be accounted for by experimental errors in reading considering the period of time which elapsed between the first and last readings. In position 7, Fig. 4, however, there was more interference owing to the air above the rider being more disturbed than the air underneath. When the rider was immediately in front, in position 1, Fig. 5, there was more difference, and as the gap decreased it became greater still. Thus in position 3, Fig. 6, between angles of plus 10 degrees and minus 10 degrees the pressure on the rear plane increases at a greater rate, particularly on the suction side, and this increase is greater still with a smaller gap, as shown in position 6, Fig. 7. Attention may be directed to the fact that this phenomenon is largely due to the suction side of the rear plane. All the curves shown indicated the total lift and the suction and compression on the plane at the various angles of inclination of the rider. In all cases the suction was considerably more than the compression when the main plane was kept at a fixed angle of 7 degrees. These diagrams appeared in "Flight" on November 20th, 1914, as a small extract from a series of lectures previously referred to. The diagrams show that by moving the rider from an angle of minus 10 degrees to plus 10 degrees with the rear plane fixed, the lift on the rear plane increases in the same way as it would if its own inclination were altered. As the gap was decreased the interference with the rear plane increased at a still greater rate. With a very small gap and change of inclination of the rider from plus 10 degrees to minus 10 degrees, the lift on the rear plane acted as if the inclination of the rear plane had been altered. Referring to the lecturer's explanation as to the burble point, it is well known that this occurs at various angles according to the aspect ratio, but whatever its reason it is clear that if one of the speaker's rider planes were placed in front of the main plane and its inclination altered suitably, the effective or apparent inclination of the main plane could be reduced as much as desired, so as to keep it below the burble point. Further diagrams, published before the war, which agreed very much with the Lecturer's own diagrams, showed that with planes of aspect ratio varying from one-sixth to nine the burble point or critical angle decreased as the aspect ratio increased and also that the peak in the curve decreases at the same time. The maximum peak effect appears to occur with a

square plane, *i.e.*, when the aspect ratio is 1, and diminishes as the aspect ratio becomes a fraction or increases above unity. With aspect ratios of 9 and over the peak appears to disappear and the curve of pressure increases continuously with increase of angle, but the increase is at a less rate after the critical angle is passed. Thus it would appear that the phenomenon known as "burbling" is not due to the air leaping away from the front edge, as stated by the lecturer, but is due to end effect. In proof of this he (Dr. Thurston) carried out at East London College, over 10 years ago, experiments with smoke jets in a moving current of air passing over planes of various aspect ratios. It was seen that involute eddies or elongated spiral eddies of opposite rotation form at each wing tip. As the aspect ratio decreased it was found that these eddies collided and interfered with each other more and more. Hence the peak in the pressure curves. This further supports the theory that the burble effect is due to end effect. He therefore disagreed with the theory advanced by Mr. Handley Page and thought that the term "burbling" was a misnomer which should be discarded. A more satisfactory term appeared to be "the aspect ratio critical angle" since each aspect ratio has its own critical angle. As the basis of Mr. Handley Page's theory does not appear to be correct it follows that the results obtained, although promising, are not the best values possible. The speaker having been over the ground himself thought he had found a more efficient method of obtaining increased support from the air. He thought his own experiments and those of Mr. Handley Page promised considerable modifications in standard aeroplane practice which will lead to increased efficiency, greater safety, and economy. He congratulated Mr. Handley Page very much indeed on the result of his experiments, with which he had no criticism. In view of Colonel Bristow's attack of the speaker for not publishing the results of his experiments before, he pointed out that the experiments were published before the war. He did not think he should be held responsible for the fact that Colonel Bristow appeared to be ignorant on the subject.

Colonel Bristow said Mr. Handley Page made a casual remark to the effect that he put only a single unit in front of the main plane in order to reduce the expense of the experiments. It was lamentable that experiments of such a vitally important character should have to be carried out in a manner that would save a few pounds in a country that spent 1,000 millions a year. It was most regrettable that there could not be some arrangement by which assistance could be given by the Government. The Society should express perturbation at the fact that such experiments were starved for want of financial encouragement. In view of this fact, however, the work done by Mr. Handley Page reflected even more credit upon him. This discovery or the practical working out of principles that were barely thought of before had opened for the first time the door of real commercial aeronautics, and its application would have a profound effect on every branch.

If any representatives of the Government Department were present they would, no doubt, agree that money should be found for experiments of this character. They heard with interest from Dr. Thurston that he discovered all this many years prior to Mr. Handley Page, and one could only regret that he did not give them the results of his knowledge early in the war, as it might have had a profound effect on the design and construction of machines. The Continental Press had recently contained a certain amount of criticism as to priority between other inventors and Mr. Handley Page, but after seeing an outline of the work done by Mr. Handley Page he thought they would all feel that there could be no justice in any counterclaims made for this discovery by anybody on the Continent.

Mr. Gnosspelius said the one thing that worried him was the ratio of lift/drag. That was really an important part of the question, because it made it absolutely necessary to have a plane which could be moved. One must be able

to close the slots, and could not work with a simple structure. He congratulated Mr. Handley Page on having found out this interesting thing, as they all got rather stuck about wings. People thought there was nothing more to do, but much bigger efficiencies should be obtained than were got at present.

Dr. A. J. Sutton Pippard said the Lecturer had up to a point succeeded admirably in making other people understand how he had arrived at his results, but there appeared to be a breakdown in the sequence when he changed from the slots fore and aft. He started with the idea that a square plane gave him better results, and then changed the direction of the slots from fore and aft to along the wing. It must have been a flash of genius which gave him that idea, as it seemed out of keeping with his previous assumption. The principal difficulties were the constructional ones. The aerodynamic results were really wonderful. The only constructional difficulty the Lecturer mentioned was the manipulation of the slots, but the construction of the separate parts of the wings would also present considerable difficulty, and in addition there was the set of the wings relative to the fuselage. When the flying range was increased to 45 degrees it would be uncomfortable for a pilot if the wings were not movable relative to the fuselage. It would be a considerable temptation to any firm operating aircraft to use these wings in order to increase the total load carried, but he very sincerely hoped part of the advantage would be used to reduce the speed of landing. He congratulated the Society on being the first to receive complete results of the model tests Mr. Handley Page had instituted.

Mr. F. M. Green said that the high values of the lift coefficient that the lecturer had found were very promising, but that nearly all the results given were wind channel experiments and not full scale results. At present we have not sufficient knowledge to predict directly from wind channel results. There is always a scale effect, and it is not known whether that effect always goes the same way. For different types of wings the lift coefficient might increase in one case with the scale and decrease in others. The lecturer had said that his results with the single slot plane machine were fully confirmed by the D.H.9 aeroplane. That was the most promising part of the paper.

The lecturer also referred to an imaginary aeroplane with a gliding angle of 15 to 1 at 120 miles per hour. That would be delightful, but he did not think that the lecturer suggested that it would be practically possible to construct such an aeroplane now. It might be possible to make such an aeroplane, but the mechanical difficulties, increase of weight, and so on were great, and its climb would probably be so small as to make it a dangerous machine to fly.

The Handley Page wing with adjustable slots would certainly help towards obtaining a machine with a good gliding angle at high speed. At the same time, it was probable this could not be done without some addition of weight to the wings and considerable difficulties in design. An aeroplane structure has to be made so light that it is always subject to considerable strain and this would make it difficult to work a number of swivelling joints.

An aeroplane with adjustable flaps at the trailing edge was constructed at Farnborough before the war. Experiments carried out on it seemed to show that the increase of weight and complication was not warranted by the possibility of increased performance.

The lecturer had suggested that the surface of an aeroplane was chosen in order to give it a definite landing speed, and that this surface was always too much for flying at full speed. In war machines this was certainly not the case. Sufficient surface was provided for obtaining the maximum performance at very high altitudes, and in fact at such heights the lift/drag ratio of the plane at full speed was about its maximum. For commercial machines the same considerations do not apply as the aeroplane will fly lower and the climb may not be quite so important. At the same time, we should proceed with great caution before deciding to adopt com-

mercial aeroplanes that do not have reasonably good climbing powers. It would be dangerous to try and get out of small aerodromes in bad weather on such machines. If Mr. Handley Page would give us some more information on the full scale results that had been obtained it would undoubtedly add greatly to the value of his excellent paper

Mr. C. C. Walker said that Mr. Handley Page had presented a large amount of valuable raw material in his most interesting paper. As to how this raw material is to be used, he indicated that machines could be designed with the help of his invention to fly at speed using a wing having the best possible value L/D.

To make a comparison between what can be achieved with the new wing and what can be done by making the best use of unslotted wings is such a difficult matter that it can probably only be left to completed aeroplanes to decide. There are, however, some general comparisons which can be usefully made.

A wing structure can be designed (unslotted) with a maximum lift coefficient of over .85 and a maximum L/D of 21. An aeroplane using this wing structure arranged to give its maximum L/D at the cruising power of the engine and at a cruising speed of 100 m.p.h., will automatically possess a reasonably good "get off" and landing speed, and will therefore fulfil the important function of using the top of a high L/D curve when in flight. If it became practicable to use higher maximum lift coefficients (maintaining the same L/D) they could be used for (*a*) improving the "get off," (*b*) for increasing the load with the same "get off," (*c*) for reducing the wing area and thus getting higher cruising speed for the same "get off" and load. The advantage under (*b*) is more limited than might be supposed because it means taking more power from the engine in order to fly level at the greatest wing efficiency than would have been the case with the smaller load, and it is doubtful if engines should ever run over $\frac{3}{4}$ full power at the most in commercial work, except, of course, for getting off the ground. If, therefore, 100 m.p.h. is found sufficient, it seems that the advantage of high lift coefficients should be shared between (*a*) and (*b*). If, however, greater speeds become necessary, (*c*) is, of course, the machine. This machine would possess a low value of L/D for the whole machine, but would nevertheless transport the same load at a greater speed than the lower lift machine which, after all, is more important than the possession of a high L/D.

Mr. Handley Page referred to the possibility of very high values of L/D for the whole machine coupled with high speeds. These features seem incompatible, for while it is, of course, true that the wings must supply their lift for the least possible drag, yet the real job is the horizontal transport of the load in the fuselage. The h.p. spent in overcoming the body drag is that spent necessarily and usefully—that spent in supplying the lift is an unfortunate necessity but is wasted so far as transport of the load goes. Thus the ideal commercial aeroplane has as little stuff as possible extra to the fuselage and contents; in other words, a rather low L/D. A machine having the highest possible overall L/D would in practice be slow, for it would have a small fuselage and big wings, and therefore a small engine and radiator.

The remarkable lift coefficient of 1.9 obtained with the multiple slots would enable an extremely fast machine (with low overall L/D) to be designed. The difficulties seem endless and staggering as regards translating the multiple slot results into an actual aeroplane, and although Mr. Handley Page disclaimed putting forward these results as anything but abstract aerodynamic data, it would be interesting to know his opinion of the ultimate prospect of going the whole hog in the matter of lift coefficients.

He thought that the fact that a commercial firm was capable of presenting an entirely original and valuable mass of research work to the world in these difficult times compelled the greatest admiration, and he would like to add his congratulations to those already tendered to the Author.

Mr. Hodgson (communicated) wished to know whether any tests had been made on wings in which the "feathers" were inclined in the reverse direction to that adopted in the "Handley Page" wing. The tip of birds' wings were inclined in this reverse direction, and it would seem strange if Nature, with her infinite resources of time and material for carrying out experimental research, had not anticipated this brilliant research of Mr. Handley Page, and still more strange if, after her age-long work, she had decided on an arrangement which was less efficient than Mr. Handley Page had been able to reach in the space of a few years.

Mr. Handley Page, in replying to the discussion, said Colonel Bristow had remarked that the Government should contribute something towards the cost of the experiments. It was satisfactory to know that they had there the Director of Research of the Air Ministry, so he presumed the message was being conveyed to the right quarter.

Dr. Thurston dealt with the question of work done previously. He (the Lecturer) showed a further slide referring to experiments carried out on the Continent with the Lachmann wing. Three weeks ago he had carried out experiments on a wing made to the sketch given of the Lachmann wing, and the results had been disappointing. With the slot closed one would anticipate that the lift coefficient of such a wing with slots would be about .7 in absolute units, and that if a lift were obtained by opening the slots one would certainly get at least that value. The maximum lift coefficient obtained on test was .55. Therefore if large lifts were obtained by those experimenters abroad who were stated to have anticipated the present investigations, they were not apparent from the tests now carried out, and one would like to find out what the exact results were. Dr. Thurston referred to the experiments carried out by him on planes. These tests were really on tandem systems of planes, with the front or rider plane moved into various positions with respect to the main plane, but in no case was the arrangement such as would give the same results as those described in the present paper. As is well known, the result from the tandem system of planes is not so good aerodynamically as when the one plane is superimposed over the other, but in no case were the experiments to which Dr. Thurston referred applicable to the present line of investigation. It might be as Dr. Thurston said, that burble was got rid of in the high aspect ratio plane and not in the square plane, but the results were against such a theory. If the total pressures were separated into the negative suction on the back of the planes and the positive pressure in the front, there was, on a high aspect ratio plane, at an early stage in the proceedings, a drop in pressure accompanied by burbling, whereas the increase in suction on the back of the plane was continuous to a very high angle of incidence with the square plane. This clearly seems to show that burbling occurs at a much later date with a square plane than with a plane of higher aspect ratio.

In reference to Dr. Pippard's remarks as to the connection between the slot fore and aft and the transverse slot, he had described in the paper the difference between the effect with a square plane and a plane of high aspect ratio. As he visualised it, with a square plane the live air fed in at the sides into the region at the back of the plane and helped to form that link which preserved the live air stream flowing over the back of the plane. Similar results were obtained by slotting a plane of high aspect ratio, allowing the air to flow in sideways over each end of the plane and so getting live air on the back. Instead of getting the air to flow in sideways in that manner with fore and aft slots, a simpler way was to slot it transversely and let the air flow in that way. So the logical sequence, instead of getting the air to turn a corner and see where it wanted to go, was to get it to follow the contour of the plane all the way.

An increase of lift coefficient of 61 per cent. and a decrease in stalling speed of 30 per cent. were sufficient to warrant the use of this type of plane. He never

imagined they were going to build machines on which the fuselage would be swung through an angle of 45 degrees, because it would be alarming to passengers to find themselves on their backs at the moment of alighting. They were dealing with an entirely different type of construction from the ordinary planes. Much higher loadings could be used, and therefore much greater weights of structure employed, and one could build more strongly without increase of structure weight. If the area of the plane were cut down to one-third, the weight could be three times as great per square foot of area.

There is at the moment, however, no need to go to the extreme length of obtaining a very high lift, but to effect the great improvements that are possible with the 60 per cent. increase in lift obtained with one slot.

In reply to Mr. Gnosspelius' statement that he could not get over the difficulty of getting a good lift/drag ratio, provided the rear edge of the forward plane fitted snugly on to the plane behind it, there was little difficulty in obtaining high value of lift over drift with the slotted type of plane when the slot is closed.

Captain Green referred to full-size results. As far as he remembered, with regard to the D.H.9 which was tested, owing to the nearness of the front spar to the leading edge it was not possible to make a slot of as nice a shape as they could have liked. A section was tested in the wind channel and a slot was cut through it, the position of the front spar being borne in mind. On the model the increase in the lift coefficient with the slot open was in the neighbourhood of 40 per cent. to 42 per cent., and on the full-size machine 35 to 36 per cent. On the full-size machine it was measured by measuring the stalling speed.

It was characteristic of high loading machines that speed was gained at the expense of climbing and ceiling, so a type of construction using high-lift planes should give economy in commercial work.

It was suggested by Captain Sayers that if more pounds per h.p. were carried one might carry people for 3½ or 5 guineas to Paris. It was questionable whether they could compete with the cut in rates owing to the French Government subsidies.

Prof. Bairstow referred to the spin and centre of pressure problems. He had found the result the other way round. The machine became nose-heavy and not tail-heavy.

Colonel Ogilvie said his old machine flew with 33lbs. per h.p., so there was hope, in these days, of being able to do it, alighting at the slow speed which he accomplished, and, he hoped, reaching a speed slightly, if not greatly, in excess of the 50 m.p.h. which he reached, but he agreed there would be difficulties if they attempted to move the fuselage through 40 degrees of inclination. He showed the results on a multi-slotted plane in order that the final development of the results might be seen, where the rear plane was vertical and diverting the air vertically downwards, rather than that he thought it was of immediate practical application. He thought immediate practical application lay in the direction of one or two slots, and these could be used for either slowing down the landing speed or increasing the top speed by increasing the loading.

A wing in the form suggested by Mr. Hodgson would call for an air-flow from the upper surface to the under surface of the plane; this result would not fit in with the air-flow distribution at high lift.

He would remind Mr. Hodgson that Nature had other problems to deal with, such as flapping, as well as folding, wings, and could deal with the problem of alighting by rotation of the wings in a much simpler way than by slots. Nature found it necessary to give the bird legs and claws, whereas the aeroplane was fitted with wheels. In spite of this, the aeroplane was mechanically more perfect with wheels than with legs.

Mr. William Cochrane (communicated): Mr. Page is to be congratulated on leaving the beaten tract as regards aeroplane wing design. It is doubtful if the slotted wing will displace the ordinary wing with improved modifications. In 1902 I patented and built a slotted wing model machine with eight sections in each wing. Although constructed wholly of corrugated metal, I found the wings had a tendency to buckle from the corners because this design is inherently weak. The angle of incidence of the planes could be varied by the aviator in flight through about 45 degrees, 22 degrees above and 22 degrees below the horizontal, so it is not novel to set the sections in a wing at a negative angle. The ideal wing will probably be a corrugated all-metal construction with one rigid arched leading arm inside the wing. The end of the arm will be capable of partial rotation to vary the angle of incidence according to requirements. I noticed the sections of the wings experimented with were very flat. Burbling would not occur so soon if the wings were more arched with a deep varying camber from the root to the tip with flexible trailing edges, following closely the section of a gull's wing. This is well-nigh impossible to produce with the system of construction at present in vogue, but with my arched leading arm system any section can be produced without weakening the wing structure. I await with interest to see what claims the British Patent Office allow Mr. Page for his invention.

Votes of thanks were passed to the Lecturer, on the motion of the Chairman, and to the Chairman on the motion of Air Commodore Brooke-Popham (Chairman of the Council of the Society).

THE EFFECT OF TEMPERATURE AND ALTITUDE OF AERODROME IN THE TAKING OFF OF AEROPLANES.

(Paper contributed to South African Association for the Advancement of Science.)

BY P. G. GUNDRY, PH.D., B.SC., F.AË.S. (LATE R.A.F.).

Introduction.

The Cairo-Cape flights of 1920 brought into prominence many peculiarities of conditions arising from the high temperature combined with high altitude of the aerodromes on the route. The conditions were for the most part new, for flight from elevated aerodromes in Europe and the United States has been made as a rule in temperate climates, where the temperature at such altitude was low. These peculiarities, which led to great difficulties for the pilots, may be divided into two classes:—

(1) Engine peculiarities, especially defects of carburation and unequal heating of the cylinder jackets owing to the high temperature of the air.

(2) Aerodynamical peculiarities, owing to the tenuity of the atmosphere.

In the former class the difficulties were not to be foreseen, and much valuable information has been obtained as a result of these flights.

The latter class of difficulty, on the other hand, was one that could have been predicted with certainty by anyone who has had experience in the testing of the performance of aeroplanes under varying conditions of the atmosphere. Much trouble would have been saved if some figures had been worked out beforehand as to the maximum load per horse-power allowable under the unfavourable conditions of low air density to be expected in the hot and high tableland of Central Africa.

As Rhodesia and the greater part of the Union of South Africa offer the disadvantageous conditions of high ground, often at elevated temperature, it seems worth while to consider in what way the ideas of aviation as obtained from experience in Europe must be modified when applied to this country.

1. The effect of Temperature and Altitude.

As a result of a vast amount of investigation with the greatest possible variety of machine during the late war, the performance of a machine in the air can be predicted with a very fair amount of accuracy. The factors which determine the air speed on the level and the rate of climb are:—

(1) The loading in pounds per horse-power.
(2) The wing loading in pounds per square foot.
(3) The density of the air.
(4) The propeller efficiency, *i.e.*, the proportion of the h.p. which is used in propelling the machine.

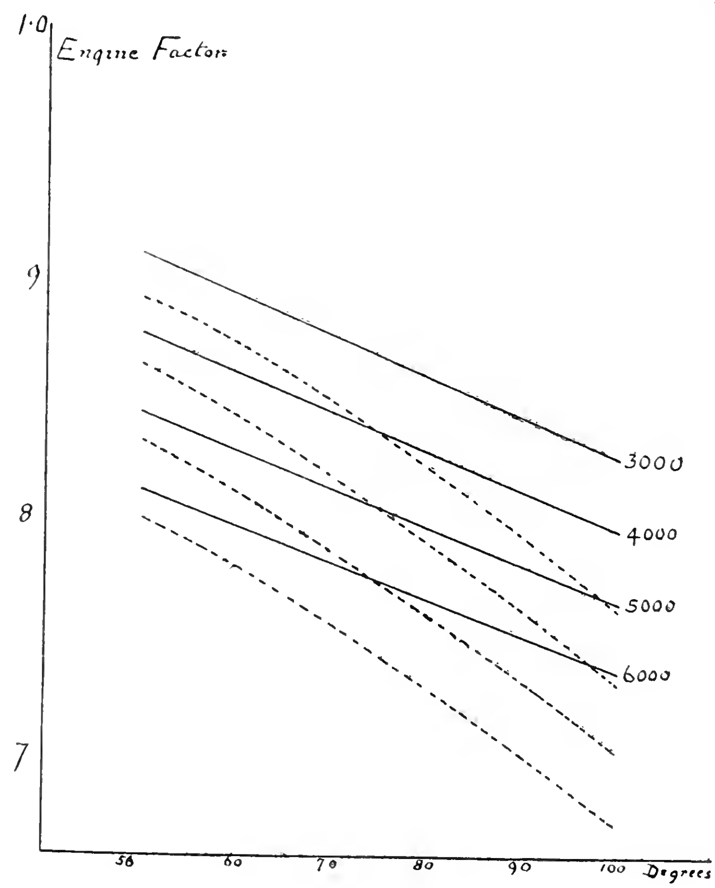
When these factors are taken into account, the performances of all machines from the lightest scout to the heaviest bomber seem to fall into the same scheme.

The propeller efficiency is the most uncertain term in the work. It may reach about 70 per cent., but the efficiency depends on the air speed, and at the low speeds of running along the ground before taking off it certainly will be considerably lower than this figure.

The most serious effect of a diminished density is in lowering the horse-power of the engine. At each stroke a smaller mass of air is drawn in. Though an "altitude control" may correct the consequent over-richness of the mixture, nothing but a motor compressor or similar contrivance will obviate the reduction of energy supplied by each stroke.

The following calculations are based on figures of reduction of h.p. with density used in dealing with performance tests during the war. I understand that these figures are considered to be too optimistic, but as it is my object to give a lower limit to the effect sought, the values are in the right direction and at any rate are not exaggerations.

Fig I



It is often stated that the tenuity of the atmosphere makes flying difficult because the air is "too thin to hold up the machine." This is erroneous in the sense usually intended. The thinness of the air also diminishes the resistance to the forward motion of the machine, and the greater air speed thereby obtained compensates for the loss of lifting power at a given speed. By far the most important effect is that of reducing the engine power.

The density of the air can be calculated when the pressure and temperature are known. In the following work the conditions are taken at 3,000, 4,000, 5,000 and 6,000 feet altitude and temperatures 50, 60, 70, 80, 90, 100 degrees Fahrenheit. The altitudes are what are called "isothermal heights," *i.e.*, heights as given by an ordinary aneroid or altimeter.

The curves of Fig. 1 show the engine factor $f(d)$ which must be used to multiply the h.p. at sea level for the same number of revs. per min. to get the h.p. actually obtained; d = the density of air compared with that at sea level under standard conditions (*i.e.*, 1,222 grams per cub. metre).

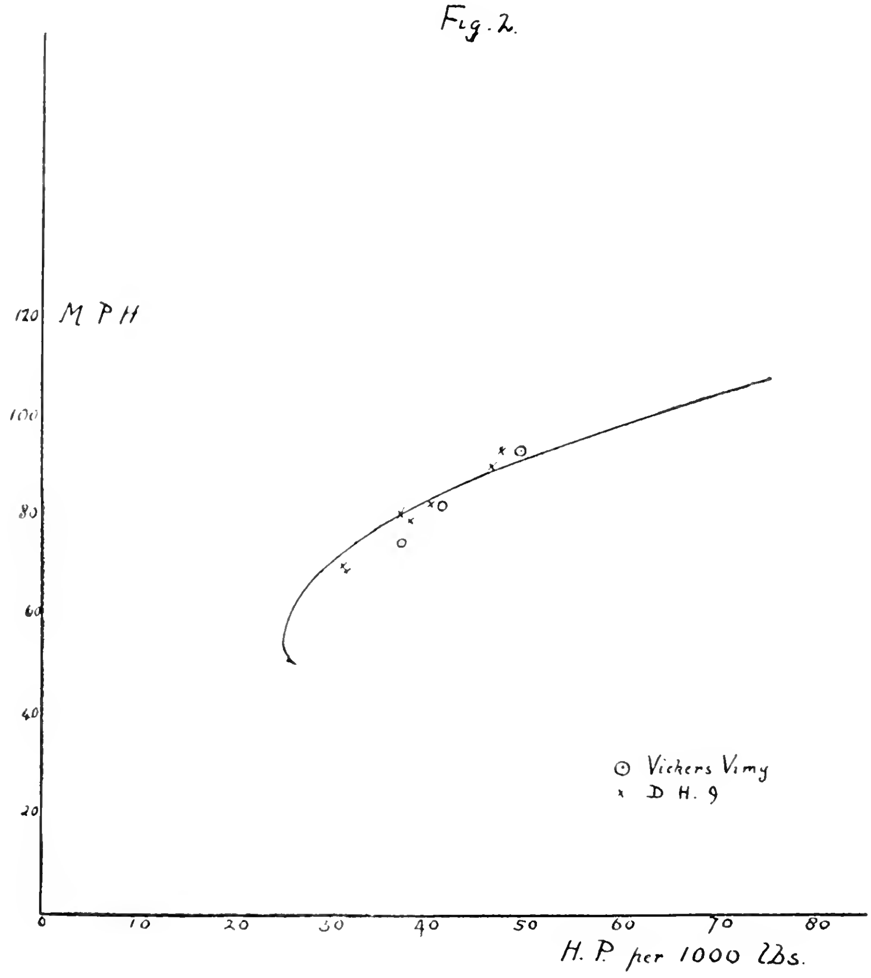
The greatest possible varieties of machines with different loadings and in air of different densities have performances which fit into the two curves given in Figs. 2 and 3 fairly well.

In Fig. 2 the abscissa is $E_0\sqrt{d} \cdot f(d)\sqrt{7/w}$ and the ordinate $V\sqrt{d}\sqrt{7/w}$.

In Fig. 3 the abscissa is $E_0\sqrt{d} \cdot f(d)\sqrt{7/w}$ and the ordinate $v\sqrt{7/w}$

where E_0 = engine h.p. per 1,000 lbs. of load.
d = density relative to air at sea level.
w = wing loading in lbs. per sq. ft.
V = level speed (air speed) in miles per hour.
v = rate of climb in ft. per minute.

Fig. 2.



It is from these figures that the following work is calculated. The way in which the density and loading come into the above quantities is the result of elementary aerodynamical theory.*

The points shown in Figs. 2 and 3 are calculated from actual tests on Vickers Vimy bombers and D.H.9 machines.

2. Length of run on ground before taking off.

Perhaps the most striking change that a pilot used to European conditions will notice in flying here is the greater run required to take off. Especially is this the case when the machine is heavily loaded and the air is hot. Lieut.-Col. van Ryneveld refers repeatedly in his technical report† to the difficulty of taking off his heavily loaded machine.

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* L. Bairstow, "Applied Aerodynamics."
† "The Aeroplane," Vol. XVIII., 13, p. 670.

" —— had to cut down more trees Shirati to take off."

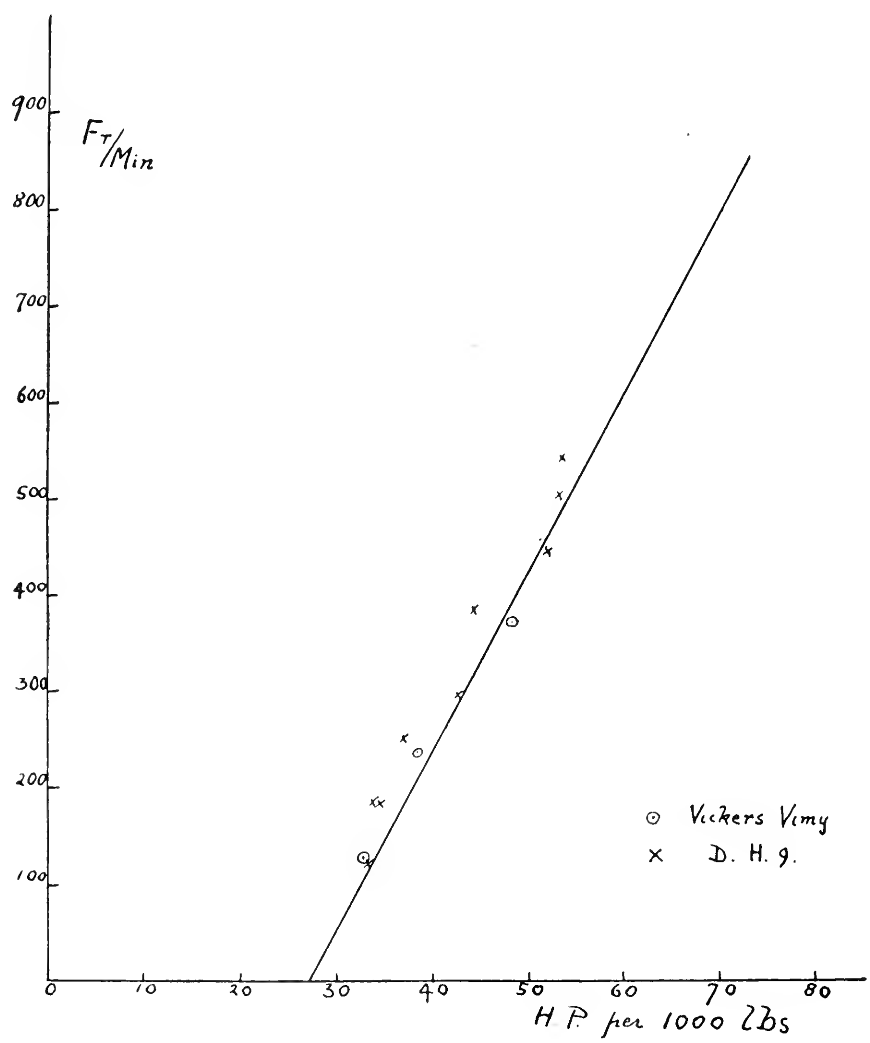
" Abercorn, only possible and safe take off here is before sunrise down slope whatever wind."

" Unexpected difficulties taking off due altitude and comparatively high temperature and moist atmosphere " (at Livingstone).

" Every take off Northern Rhodesia was touch and go for the first few minutes, tail skid scraping trees."

And so on.

Fig 3.



The following theoretical considerations will enable us to estimate the effect of altitude and temperature (*i.e.*, lowness of density) on the length of run to take off. The least favourable case of no wind is taken.

We can divide the run to take off into two portions:—

(1) A run with tail down until some speed, say 20 miles per hour, is attained. This distance, which is quite short, will be unaffected by the density of the air. The speed is too slow for the air resistance to play an important part.

(2) A run with tail up, in which the speed rises from 20 m.p.h. to the flying speed. This is by far the more important and greater portion of the run. We will assume that the pilot takes off at the minimum flying speed and that we may neglect the frictional forces connected with the contact with the ground. In this

way we shall get an under estimate of the length of the run required, for he will probably not lift the machine from the ground until he has some slight reserve of speed over the minimum flying speed.

Let s = the distance of the run from the place where the speed is 20 m.p.h.

P = the h.p. of the engine.
η = propeller efficiency.
v = speed in feet per second.
m = mass of the machine in pounds.
g = 32.2 ft. per second per second.

Then, thrust — resistance = mass × acceleration.

The thrust is $\eta\, 550\, P/v$. Resistance = Kdv^2.

$$\eta\, 550\, P/v - KdV^2 = (m/g)\, v\, (dv/ds) \qquad (1)$$

To find K, we will assume that the machine in the tail-up position is in the attitude for level flight, for which the air speed is l ft./sec.

Then

$$\eta\, 550\, P/l = Kdl^2$$
$$\eta\, 550\, P\, (1 - v^3/l^3) = (m/g)\, v^2\, (dv/ds)$$

This leads to

$$s = (m/g\eta\, 550\, P)\, (l^3/3) \log (1 - 20^3/V^3)/(1 - V_0^3/V^3)$$
$$= (0.1368/\eta)\, (V^3/E) \log (V^3 - 20^3)/\, (V^3 - V_0^3)$$

where V = level speed in miles per hour.
V_0 = minimum flying speed in m.p.h.
E = h.p. per 1,000 lbs.

In this formula V and E both diminish with diminishing density, but the change of V is small compared with that of E. V_0 on the other hand increases as the density gets less, being proportional to $1/\sqrt{d}$.

When $V_0 = V$, *i.e.*, at the ceiling, the length of run becomes infinite.

3. Application to the Silver Queen II. (Vickers Vimy Machine).

The weight of the Vickers Vimy machine without load is only known to me when the engines were Sunbeam Maoris. The difference in weight of these engines from that of the Rolls-Royce Eagle VIII. is known, and the weight I have taken cannot be far from correct.

I have taken two loadings as follows:—

1.	Machine light	6,900
	Fuel and oil	1,200
	Crew and accessories	720
	Total weight	8,820 lbs.
2.	Machine light	6,900
	400 galls. petrol	2,880
	30 galls. oil	270
	Crew, spares, etc.	950
	Total weight	11,000 lbs.

As far as report goes, the latter must have been about the load with which Col. van Ryneveld left the Bulawayo aerodrome with the Silver Queen II. on its last flight.

The former load we may speak of as a "light load." It represents petrol

for about three and a half hours flight calculated from the average rate of consumption given by Col. van Ryneveld, viz., 40 gallons an hour.

For the purpose of calculating the horse-power it is necessary to take the rate of revolutions per minute into account. I have taken 1,550 R.P.M. for this. For this rate the h.p. of each engine at sea level (density 1) is 315, as given by average bench tests. As the R.P.M. will be lower than this for the early part of the run, we shall get for this reason again an under estimate of the run required.

The wing area (lifting surface) of the machine is 1,387 square feet. We have therefore for the two cases:—

Light load $E_0 = 71.5$ $w = 6.36$ lbs. per sq. ft.
Heavy load $E_0 = 57.3$ $w = 7.94$,, ,,
E_0 = engine horse-power per 1,000 lbs. at sea level.
w = wing loading.

Another factor in making the calculation is the landing speed or minimum flying speed. This (as in the case of all air speeds considered) is the true air speed, *i.e.*, the indicated air speed divided by $\sqrt{d}$. I believe that 60.m.p.h. will be a fair estimate to take for the light load at sea level. The correctness of this figure will not greatly affect the comparison of the different conditions. With variation of the conditions this speed will be proportional to the square root of the wing loading and inversely as the square root of the density. The greater speed to take off with diminished density and increased loading will have a marked effect in lengthening the run.

The propeller efficiency, as remarked above, is the most uncertain term. It attains the value of 70 per cent. at the best speed for the propeller, but in the low speeds of run along the ground it will certainly be less than this. For purposes of comparison its value does not matter. We will take it 60 per cent., which is probably a good deal too high for the early part of the run.

With the above data we can calculate the minimum run to take off at sea level and at different altitudes and temperatures.

TABLE 1.

Light load. Total weight 8,820 lbs.
Run to take off in feet.
At sea level 321 ft.

Altitude. / Temp.	3000	4000	5000	6000 ft.
50 F.	418	461	513	570
60 F.	436	486	541	602
70 F.	461	519	570	639
80 F.	486	542	603	674
90 F.	514	574	637	711
100 F.	542	604	674	750

TABLE 2.

Light load.
Ratio of run to that required at sea level.

Altitude. / Temp.	3000	4000	5000	6000 ft.
50 F.	1.30	1.44	1.60	1.78
60 F.	1.36	1.51	1.69	1.88
70 F.	1.44	1.62	1.78	1.99
80 F.	1.51	1.69	1.88	2.10
90 F.	1.60	1.79	1.98	2.22
100 F.	1.69	1.88	2.10	2.34

TABLE 3.

Heavy load. Total weight 11,000 lbs.
Run to take off in feet.
At sea level 601 ft.

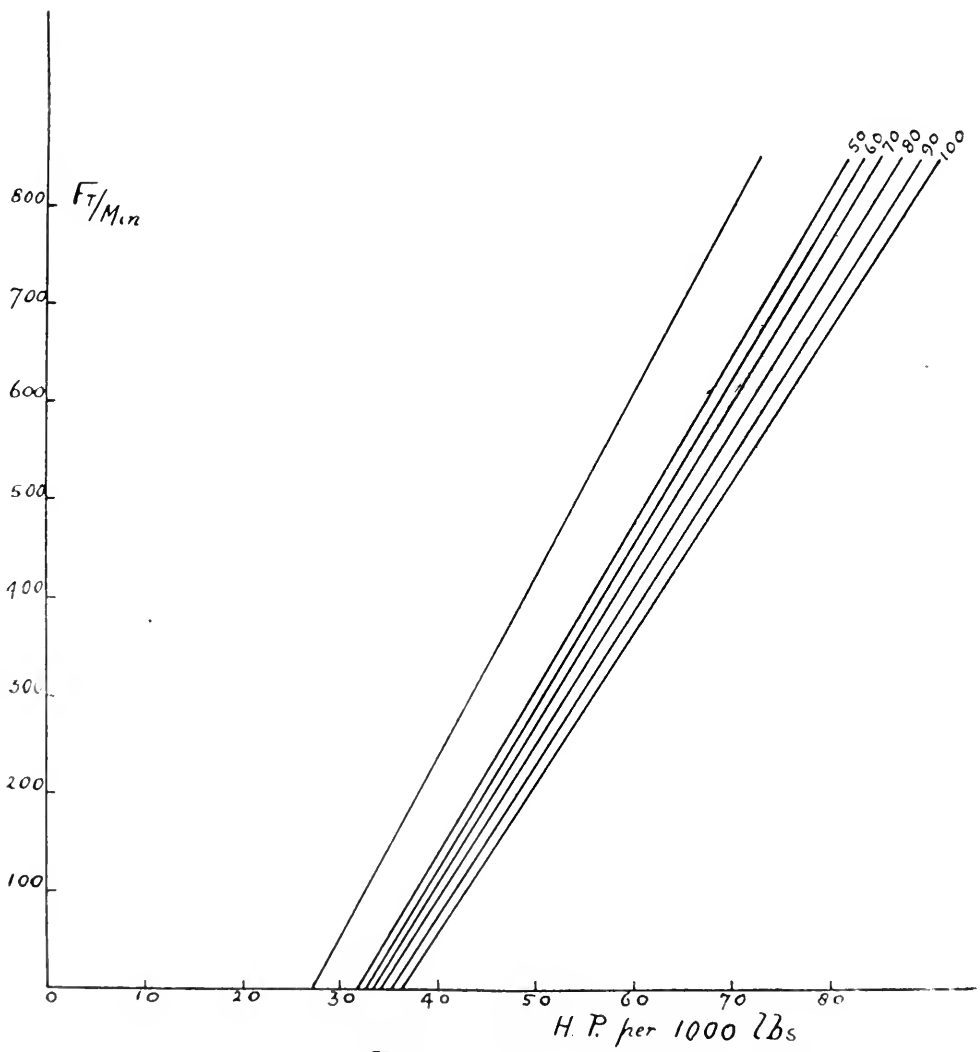
Altitude. Temp.	3000	4000	5000	6000 ft.
50 F.	796	885	994	1124
60 F.	832	935	1046	1193
70 F.	880	991	1117	1268
80 F.	934	1050	1190	1352
90 F.	990	1117	1263	1443
100 F.	1050	1191	1341	1542

TABLE 4.

Heavy load.
Ratio of run to that required at sea level.

Altitude. Temp.	3000	4000	5000	6000 ft.
50 F.	1.32	1.47	1.66	1.87
60 F.	1.39	1.56	1.74	1.99
70 F.	1.46	1.65	1.86	2.11
80 F.	1.55	1.75	1.98	2.25
90 F.	1.65	1.86	2.11	2.40
100 F.	1.75	1.98	2.23	2.55

Fig 4.



Rate of Climb at 3000 ft

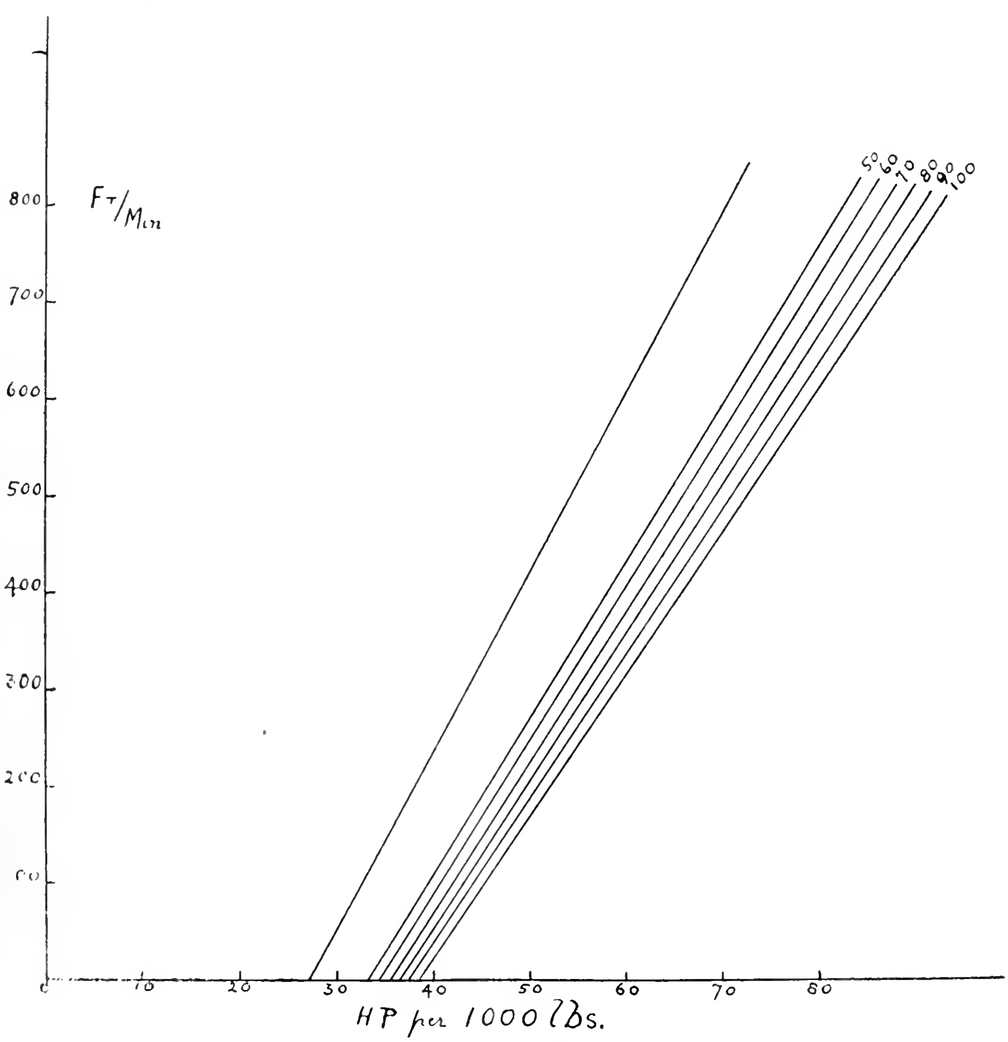
From the above results we see that at Bulawayo, for example, with a temperature of 90° F., an aerodrome in every direction nearly twice as large as under ordinary European conditions would be required; while at places of altitude 6,000ft. with a temperature of 100° F. the linear dimensions of the aerodrome should be two and a half times those of the aerodrome in England required for the same machine.

4. Rate of Climb from the Aerodrome.

Hardly second in importance to the length of run to take off is the rate at which the machine will climb out of the aerodrome. Not only has it to clear obstacles such as trees on the boundary, but it must rise sufficiently high to be out of the disturbed condition of the atmosphere in the neighbourhood of surrounding hills and kopjes. The rate of climb under different conditions of altitude and temperature can be calculated from the curve in Fig. 3. In Figs. 4, 5, 6, 7, we have the curves giving the rate of climb for any ground horse-power per thousand pounds, and for the six different temperatures and four different altitudes, the curve for sea level being given in each case for purposes of comparison. All these curves apply to the case of a wing loading of 7 lbs. per square foot.

Calculation of the rate of climb under the different conditions leads to the following results:—

Fig. 5



Rate of Climb at 4000.ft.

TABLE 5.

Vickers Vimy. Light load. Total weight = 8,820 lbs.
Rate of climb in feet per minute.
At sea level 845 ft. per min.

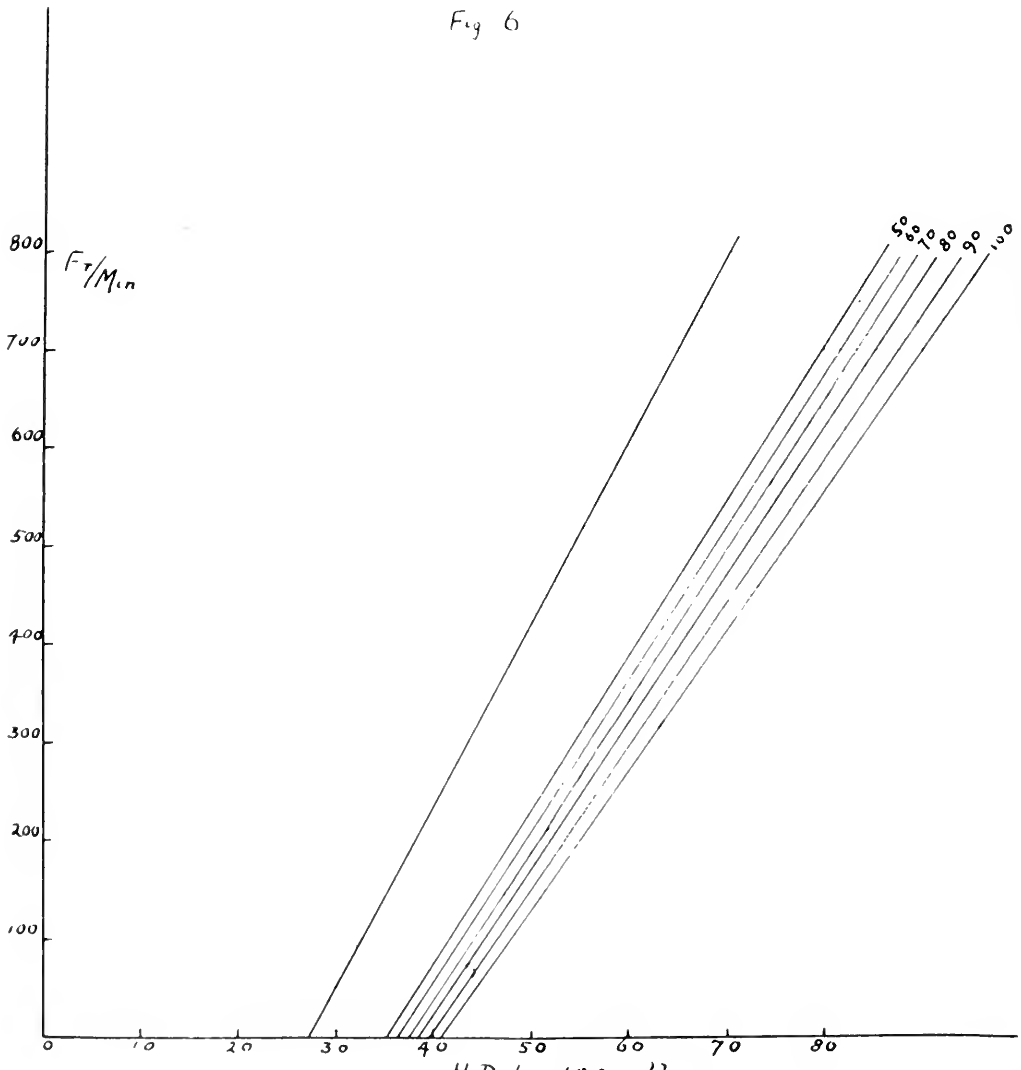
Altitude. Temp.	3000	4000	5000	6000 ft.
50 F.	696	648	597	543
60 F.	674	619	568	516
70 F.	648	597	542	487
80 F.	619	568	516	464
90 F.	597	542	486	438
100 F.	568	515	463	417

TABLE 6.

Vickers Vimy. Heavy load. Total weight = 11,000 lbs.
Rate of climb in feet per minute.
At sea level 523 ft. per min.

Altitude. Temp.	3000	4000	5000	6000 ft.
50 F.	396	360	312	267
60 F.	377	332	290	243
70 F.	358	308	265	221
80 F.	332	288	244	201
90 F.	308	265	222	180
100 F.	288	244	201	162

Fig 6



Rate of Climb at 5000 ft.

For purposes of comparison we may take the results for the D.H.9 machine with the Siddeley Puma engine ("Voortrekker"). The loading is taken as follows:—

Machine light	2,200
Fuel and oil	500
Crew, etc.	360
Total weight	3,060 lbs.

Wing area 436 sq. ft. R.P.M. 1,350. Horse-power (sea level) 242.
Horse-power per 1,000 lbs. 79.1.
Wing loading 7 lbs. per sq. ft.

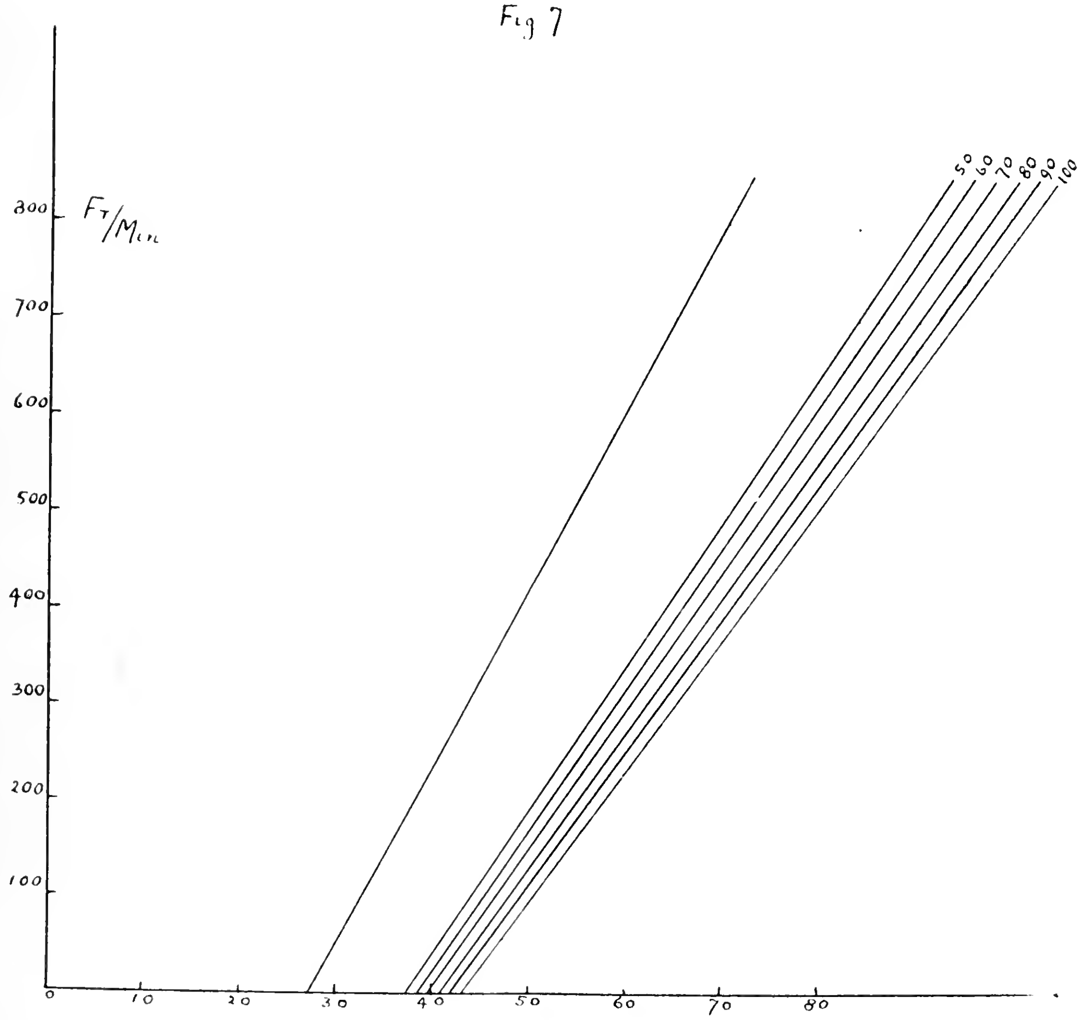
TABLE 7.

"Voortrekker."

Rate of climb in feet per min. at sea level 965 ft. per min.

Altitude. Temp.	3000	4000	5000	6000 ft.
50 F.	800	740	688	626
60 F.	772	715	662	600
70 F.	740	685	636	568
80 F.	712	655	608	542
90 F.	685	628	568	518
100 F.	660	600	542	500

Fig 7



H.P. per 1000 lbs

Rate of Climb at 6000 ft.

It will be seen that the rate of climb of the Vickers machine loaded as it left Bulawayo falls to a very low value for high altitudes and high temperatures. Taking the extreme case of 6,000 ft. at 100° F. the rate of climb is only 162 ft. per min. It is also clear that the superior performance of the Voortrekker, which finished the flight to Cape Town, is not due, as was supposed by some, to superiority of the machine or its engine, but merely to the fact that its loading was more suitably tempered to the disadvantageous conditions of altitude and temperature.

5. Effect of Humidity.

It is worth while considering the effect of water vapour in the air on the performance of the machine. For a given pressure the amount of dry air in a given volume diminishes with increase of humidity, and the effect, unimportant at low temperatures, might become important at high temperatures. For example, saturation at 100° F. will decrease the relative density of the dry air from 0.746 at 6,000 ft. to 0.689, a change of 7.6 per cent. The factor of reduction of engine power is thereby reduced from 0.736 to 0.677, a reduction of 8 per cent. The relative density of the dry air is what must be used in the engine factor, since the vapour drawn in at each stroke is passive as far as combustion is concerned. On the other hand the aerodynamic effect of humidity is negligible, the square root of the density being very little altered by the presence of water vapour. In Fig. 1 the alteration of engine power factor for presence of saturated water vapour is shown.

It appears as if even the extreme case of saturation at 100° F. would only produce about 8 per cent. increase in the run to take off.

It does not appear therefore that (apart from the effect on the fabric, and the extra weight due to deposition) humidity should have much detrimental effect on the performance of the aeroplane.

6. Conclusion.

It is clear from the above considerations that the views as to possible loading per horse-power gained from experience during the war, more particularly from bombing machines, must be modified when applied to flight in Central and South Africa. One of three courses is open :—

Either (1) our aerodromes must be very much larger (say twice as big as under European conditions).

Or (2) the loading of the machines in pounds per horse-power must be considerably reduced.

Or (3) some effective way of overcoming the loss of horse-power with diminished density must be employed.

With regard to (2), long stop flights must give place to shorter flights of three or four hundred miles or less. Thereby the load of petrol may be reduced and smaller machines may be used.

With regard to (3), as far as I know all such devices of forced draught into the engine that have been tried under European conditions have not been found to give extra horse-power commensurate with their extra weight. It is however a question worthy of consideration whether under the different conditions of this country some such device may not be worth while adopting.

THE TECHNIQUE OF FLIGHT.

Lectures delivered to the Scottish Universities in November, 1920,

BY SQUADRON LEADER R. M. HILL, M.C., A.F.C.

LECTURE II.

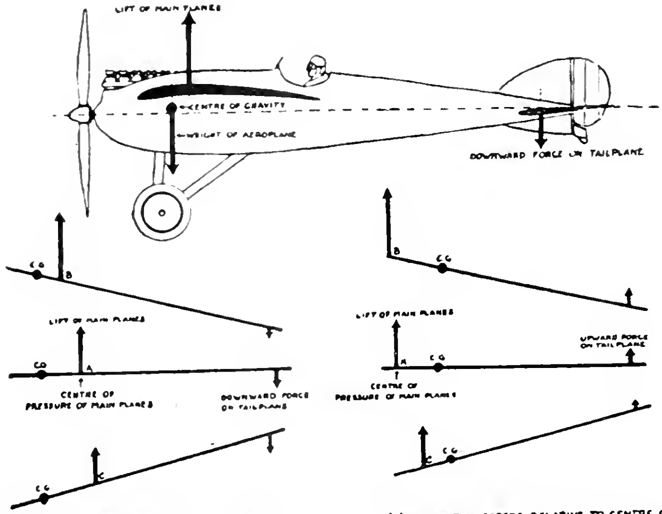
In my last lecture I promised to try and show how the pilot can foresee and effectively eliminate practically all the danger which attends the art of flying. You will probably notice that most of the danger arises, at least indirectly, from some misbehaviour of the engine; so that in estimating the danger I shall be compelled to lay considerable emphasis on the possibility of engine failure, in spite of the fact that it is comparatively remote. If we look back to the infancy of any mechanical means of locomotion, we realise how unreliable it was in the initial stages; we may therefore look forward with absolute confidence to the future reliability of the aero engine and its installation.

Every day almost marks an improvement, and if the early pioneers who lost their lives could trace its development what surprise they would express! At the same time the possibility of one unreasonable engine failure is a menace to the whole of flying, which cannot and must not be blinked at. To the engine designer it must afford the stimulus towards improvement in engine design, on the part of the aeroplane designer it must be met by the will to explore every means of mitigating its effects, and on the part of the pilot of to-day by the firm resolution so to study the art of flying that he may not be caught unprepared and indirectly diminish the confidence of the public, upon the active support of whom rests the future of civil aviation.

Apart from learning to nurse his engine sympathetically, so that he may get the best out of it and make the chance of engine failure as remote as possible, the most urgent problems for the pilot to study are the balance of his aeroplane, what powers his control surfaces give him, and how far they extend. Hitherto, when considering the forces acting on the wings and on the aeroplane, I considered them without reference to the couples called into play. How then is the balance of an aeroplane maintained? The problem naturally divides itself into two parts—the lengthways, or longitudinal balance; and the sideways, or lateral balance. As the lateral balance is closely associated with all the problems of turning, it will be taken as embracing any motion about the longitudinal and vertical axes of the aeroplane. Both these problems have long been the subjects of close investigation, both by mathematicians and by flying men, and the practical results of the study of longitudinal stability are far more evident than those of lateral stability in the aeroplane of to-day. If the aeroplane is deficient in one, the helpful qualities arising from the other are seriously impaired, for in practical flying there is hardly a manœuvre which is not coloured and diversified by the most complicated kinds of motion. From one side the problem is attacked by the flier, who views a complex motion as a natural manœuvre, and on the other by the scientist who attempts to analyse the motion and build up a theory about it.

I will try and give an analysis of the longitudinal balance of an aeroplane as simply as I can. In order to bring out the fundamental truths, I have specifically

neglected certain factors which modify and refine the conclusions, but do not substantially affect them.



WING AND TAIL FORCES RELATIVE TO CENTRE OF GRAVITY IN A STABLE AEROPLANE.

WING AND TAIL FORCES RELATIVE TO CENTRE OF GRAVITY IN AN UNSTABLE AEROPLANE.

At the top of this diagram is a picture of a monoplane with its wings and tail plane shown in section. The position of the centre of gravity is indicated, and the arrow shows a force representing the weight acting vertically downwards. Another arrow shows a force representing the lift of the wings acting vertically upwards through the centre of pressure of the wings, the centre of pressure being the intersection of the line of the resultant air force on the wing and the chord of the wing. The chord of the wing is a line joining its leading and trailing edges. This force may be resolved into any directions you like, but it is most convenient for our purpose to resolve it into the lift component acting vertically, and the drag or resistance component acting horizontally. In the picture I am simply concerned with the lift of the wings. You will notice that there is an arrow showing a downward force on the tail. The couple produced by the tail must of course be equal and opposite to that caused by the wings, if the aeroplane is in balance or in "trim."

Supposing now that we have the aeroplane in balance or equilibrium, you all know that this may be of two kinds, stable or unstable. This, of course, means that should the aeroplane be disturbed from its condition of balance, if stable it will return to that condition, if unstable it will diverge further and further.

In order to find whether the aeroplane is going to be stable or unstable let us examine the variation of the forces if the aeroplane is disturbed. At a given speed, as we saw before, you must be flying at a certain angle of incidence, and this angle and no other will satisfy the requirements of flight, which will, in its turn, determine the position of the centre of pressure relative to the wing chord. But if the angle of incidence be increased or decreased the centre of pressure moves, and the way in which it moves is not conducive to balance. In a general way, at least within the range of flying angles, if the wing is moved to a bigger angle to the relative wind the centre of pressure moves forwards, thus tending to push the wing to a bigger angle still; and if to a smaller angle, backwards, with the reverse effect. Thus any disturbance always tends to upset the wing.

Again, if the wing is moved to a bigger angle, simultaneously with the forward movement of the centre of pressure, the lift force increases due to the increased angle; whereas if the wing is moved to a smaller angle, simultaneously with the retrogression of the centre of pressure, the lift force decreases, due to the decreased angle.

Similarly, if the aeroplane is disturbed the force on the tail is affected by its

change of angle of incidence corresponding with that of the wings. The movement of its centre of pressure can be neglected as it is relatively so small compared with its distance from the centre of gravity of the aeroplane.

Let us now examine the effect of the position of the wings relative to the centre of gravity. I have chosen for the lower diagrams two extreme cases, the left hand one with the centre of gravity well forward, so that it is on the whole in front of the centre of pressure, and the right hand one with the centre of gravity well back, so that it is on the whole aft of the centre of pressure. These conditions may not accurately represent any particular aeroplane, but for comparative purposes they illustrate sufficiently well the principles involved.

Before considering them in detail let us get clear about the operation of the forces which produce the various couples. First we have the lift force of the wings and the movement of the line of action of this force; and secondly we have the force on the tail.

Take the left hand case in the diagram, with the centre of gravity forward. Let us suppose that for a certain condition of flight the lift force is as shown at A. This is behind the centre of gravity and is tending to nose dive the aeroplane. Therefore the tail has to exert a downward force, as you see, to balance this; that is, the tail has to be set at a negative angle to the wings. The aeroplane is then balanced and is said to be in trim.

Now let the aeroplane be moved by a wind gust to a larger angle. The lift force is then as shown at B, and its line of action has moved forward. The lift force, however, has increased and the downward force on the tail has decreased owing to the tail being now at a smaller negative angle to the relative wind. Thus the increased force on the wings combined with the reduced downward force on the tail tend to overcome the opposing effect of the forward movement of the centre of pressure, and to put the nose of the aeroplane down and restore it to its original attitude.

Again, let the aeroplane be moved by a wind gust to a smaller angle. The centre of pressure moves back, but the lift force shown at C decreases and the downward force on the tail increases. The reduced lift force of the wings, combined with the increased downward force on the tail, tend again to overcome the opposing effect of the retrogression of the centre of pressure, and again to restore the aeroplane to its normal attitude. This is the case of a stable aeroplane.

Take the right hand case in the diagram, with the centre of gravity back. When the aeroplane is moved to a larger angle the lift force shown at B increases and its line of action moves forward; while the force on the tail, which in this case is upward in order to balance the aeroplane, increases. Now you can see that the increase of lift force, combined with the forward movement of the centre of pressure, tends to overcome the righting moment of the tail and push the nose of the aeroplane up more and more. Similarly, if the aeroplane is moved to a smaller angle, the nose tends to be pushed down more and more. This is the case of an unstable aeroplane.

You will see that the tail always calls into play a restoring couple; but in the stable case the only thing operating against stability is the movement of the centre of pressure, while in the unstable case, both the movement of the centre of pressure and the variation of the lift force operate against stability. This is solely due to the position of the wings relative to the centre of gravity. If the centre of gravity is forward, the aeroplane tends to be stable; if back, the aeroplane tends to be unstable.

The larger the tail the larger its righting effect. The size of the tail, however, cannot be increased indefinitely owing to the injurious effect it would have on the longitudinal control. With this reservation then we may say that longitudinal stability depends on the position of the wings relative to the centre of

gravity and on the size of the tail. In actual practice the area of the tail is frequently about one tenth of that of the main planes, and the centre of gravity is about a third of the wing chord from the leading edge.

It will be seen that for some positions of the centre of gravity the wing and tail moments may approximately balance each other throughout the whole normal range of angles and corresponding flying speeds. The aeroplane is then said to be neutral, and such aeroplanes are extremely pleasant to handle. When we come to examine longitudinal control it will then be obvious why such an aeroplane is termed pleasant.

Before leaving the question of longitudinal balance I should like to say one more thing about the tail. In considering the angle of the tail relative to the wings I omitted any consideration of the downwash of the wings. As the wings pass through the air they impart to it a downward flow. The tail is naturally affected by this; and the actual angle of the tail to the wind which meets it in flight is not what it appears on a drawing, but some angle which depends on the downward flow of the air behind the main planes. If the tail were shown at a negative angle relative to the main planes on a drawing, it would be made more negative still by the downwash in flight.

I have tried to give you some idea of the longitudinal balance and stability of an aeroplane; I will now say something about the lateral balance. This is a more difficult problem and far less is known about it. To be laterally stable an aeroplane should, if left to itself, continue in its initial direction and keep on an even keel; or if its motion is disturbed, return to these conditions.

First, the motion of falling over sideways is intimately connected with the motion of turning. Suppose you are sitting in an aeroplane and it commences to drop its starboard wing; that is to say, rotate in a clockwise direction as far as you are concerned. The weight of the aeroplane is acting vertically downwards and the lift is normal to the wings, so that with the starboard wing dropped these forces no longer balance each other. The aeroplane therefore has to sideslip to starboard, until the introduction of a side force on the aeroplane due to the wind blowing on the side of the body again brings the forces into balance. At the same time, however, a force is brought into play on the side of the fin which tends to turn the aeroplane to starboard. Thus a turning motion is inevitably introduced. People talk of lateral and directional stability as separate things, but it is really impossible to consider them as such, and that is where the complication comes in.

You know that aeroplanes are fitted with a fin behind to increase the side area of the aeroplane aft of the centre of gravity, relative to that in front. If you have too little fin area aft the aeroplane tends to spin round and go tail first, which is called spinning instability. On the other hand, if you have too much fin area aft, during a sideslip, the effect of the excessive fin is to swing the tail round and gradually push the aeroplane into a steep spiral. The danger arising from too little fin is the more serious of the two, and by far the more commonly met with.

Again, on nearly all modern aeroplanes, the planes are not fitted in a straight line from tip to tip, but are inclined at a small angle to the horizontal, anything up to 5°. This is called the dihedral angle, and the effect of it is to call into play a righting couple if the aeroplane is rolled over sideways, provided it is flying at normal angles of incidence.

Suppose the starboard wing drops. The aeroplane, as was explained before, will commence to sideslip to starboard. Therefore the relative wind does not come from the front but from the starboard quarter, which means that it virtually blows more under the starboard wing and tends to blow on top of the port wing, due to the dihedral angle. This idea can be grasped if you imagine the extreme

case of the aeroplane travelling absolutely sideways, which means that the relative wind would blow from the starboard wing tip to the port wing tip. Hence the starboard wing lifts more and the port wing less, so tending to restore the aeroplane to a level keel. As a matter of fact, there are very few aeroplanes to-day where a degree of lateral stability suitable to modern requirements has been attained, and that is why I say less about it.

I told you in my first lecture that the early aeroplanes were all unstable; this was so because the idea of making them stable never occurred to men who were entirely concentrated on getting aeroplanes to fly at all. Then, later on, the want of stability was felt, and men like the late Edward Busk began to develop it in practical form. But again its development suffered a curious check. The war came, and pilots immediately began to demand aeroplanes with the maximum manœuvrability in order to get the best striking position in aerial fighting and to dodge the enemy's bullets. It was not until you met an enemy scout and you found he had a gun which barked quite as unpleasantly as yours that you realised what high manœuvrability really meant. Now you can see that a highly stable aeroplane, if trimmed at a certain speed, is always wanting to return to that speed. If you want to make a swift and sharp divergence from that speed, say to cock the aeroplane up suddenly to a big angle to shoot at an enemy above you, you have to use your elevators to do it; you cannot consult the aeroplane's wishes on the subject. It wants the whole time to return to its own natural speed, and you have to overcome its wishes; in actually doing so you have to use up part of your elevator control that might otherwise be available for cocking up the nose. The limiting case might arise when you had used up all your elevator angle in overcoming the aeroplane's wishes, and still had not cocked up your nose enough to get your sights on the enemy; or it might be that you wanted to dive on him and could not get the nose down enough for the same reasons. I admit I have exaggerated in order to bring the point home, but it will be understood that the more stable the aeroplane is the greater the force you will have to exert on the controls to overcome its wishes and do what you wish, and consequently you will say that the controls are, comparatively speaking, heavy. Now you can see why an aeroplane is actually pleasanter when it is about neutral, that is, when you do not have to exert much force to make it do what you want.

Next, what about the case of the unstable aeroplane? If it is balanced at a certain speed, then at larger angles and correspondingly lower speeds, it wants to cock its nose up, while at smaller angles and higher speeds it wants to dive. This time you actually have to employ force on the controls to right it, instead of as in the stable case, to make it diverge; but for manœuvring this is not such a handicap as it might at first appear. The essential thing to get hold of is that from the fighting pilot's point of view, the rapid lead off of the manœuvre is what he wants, in order to get his sights on the target quickly. He does not mind so much if he has to exert a little force to right the aeroplane. If he wants to point his nose up quickly, or point it down, the unstable aeroplane helps him because it is naturally trying to do that all the time. In any case the control forces on an unstable aeroplane are relatively smaller than on a stable one, owing to the fact that the tail is usually smaller.

As was shown before, there are two main factors which decide the stability characteristics of the aeroplane; and there seem to be certain harmonious combinations of these factors that produce an aeroplane in which the exertion of large control forces is not required at any speed, an aeroplane which pilots would call responsive, yet one which would look after itself, at any rate to a large extent, should the pilot leave it alone. If positive stability were arrived at by employing an abnormally large tail with the centre of gravity still kept comparatively far back, as might be possible, the aeroplane would certainly feel unpleasant and would not be liked. The clever designer would achieve stability by a harmonious

combination of the factors, without the undue exaggeration of either. The general opinion of fighting pilots seems to be that an aeroplane is most handy on the control for fighting when it is nearly neutral. If it can be made just on the stable side of this without materially impairing the control, then a great advantage is secured from other points of view. In any case extremes of stability or instability are to be avoided.

Now that the requirements of civil aviation are so prominent there is more demand still for stability. High manœuvrability can give way to stability to a greater extent; you do not want such high manœuvrability for a commercial aeroplane, but you do want it to be able to look after itself when you have to fly through fog, clouds or darkness. Even then there is still such a thing as having the aeroplane too stable; for besides the unpleasant characteristics referred to, excessive stability, with all its good points, introduces certain other disadvantages.

I have constantly referred to the pilot's having to exert force on the controls to carry out manœuvres, and have pointed out how an aeroplane, if very stable, is said to feel heavier than it would feel if neutral or even unstable. It is a difficult thing to define control quantitatively, and hitherto the pilot has generally been relied on to say whether the control feels heavy or light. More recently, however, efforts have been made to measure the force actually exerted by the pilot on the control column, I may say with considerable success. Instead of pushing direct on the control column, the pilot pushes on a spring attached to it, and the force is shown in pounds by a needle on a dial, in short, an attempt is being made to relate the pilot's description of the feel to an actual measured force.

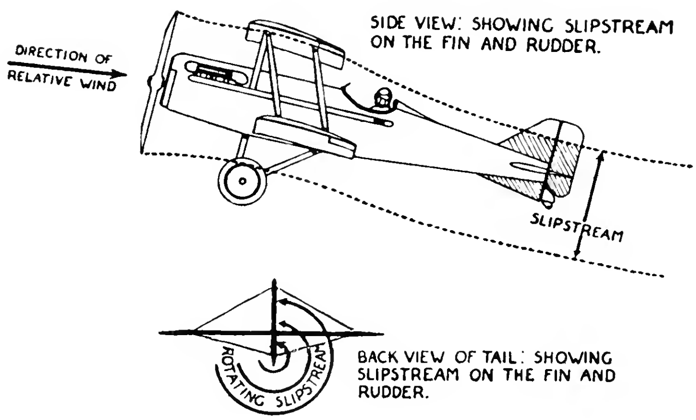
Even in a very small aeroplane the pilot has to exert some force on the controls to manœuvre it; as the aeroplane becomes larger, among other things its moment of inertia increases, and the pilot has to exert greater forces, until a limit is reached where he is not strong enough to control the aeroplane under all conditions. Thus, in a general way, if the inherent characteristics of the aeroplane are neglected, its mere size is very largely responsible for the magnitude of the control forces; and a small aeroplane is always lighter than a large one. This means that in large aeroplanes difficulties of control usually arise because the pilot has not the strength to exert the force necessary to right the aeroplane; and in small aeroplanes because he does not act quickly enough owing to the inherent quickness of movement of a small aeroplane and the liability of his being caught unawares.

I pointed out that if a stable aeroplane had the tail set to balance it at a certain speed, to fly it at any other speed it required a certain force, which is provided by the elevator. To get over this disadvantage most modern aeroplanes are fitted with an adjustable tail plane, operated by a self-locking mechanism, which can be moved in flight. The aeroplane can then be trimmed throughout a large range of speeds, and no force need be used with the elevator to balance it, so that all the power of the elevator is available to manœuvre the aeroplane.

I have hitherto considered the balance of the aeroplane without reference to the effect of the engine; the engine I have merely regarded as giving the power necessary to maintain the speed; but it also affects the balance of the aeroplane. In a modern aeroplane, as you open or close your throttle the balance of the aeroplane is affected, and it is extremely important for a pilot to realise how it is affected. I will take the most important way only; the effect of the propeller slipstream.

Take the propeller slipstream. The airscrew can only give thrust by accelerating air backwards. The air it accelerates is the air that it meets as it travels along. It throws this air backwards as it were in a jet, which is termed the slipstream; consequently the tail of the aeroplane feels an increased airspeed, and so has forces on it larger than when the engine is shut off. Again, the engine has to supply a certain couple or torque to drive the propeller round; this torque

is then applied by the propeller to the air, and as a result the slipstream has a rotational motion in addition to its increased speed. The air in the slipstream is washed downwards in a similar way to the remainder of the air encountered by the planes.



The diagram shows the approximate path of the slipstream; you see it strikes on the tail and the lower parts of the fin and rudder. If the engine is shut off the slipstream disappears, and the tail plane, fin and rudder are no longer affected, so a change is felt in the balance of the aeroplane. If the tail is set, as it usually is, at a negative angle, the slipstream increases the downward force and pushes the nose of the aeroplane up, making it feel tail heavy; conversely, the absence of slipstream makes the aeroplane feel relatively nose heavy. If the engine fails suddenly, the aeroplane becomes out of balance, and this is very disconcerting to the pilot if he is not on the look out for it.

If the fin and rudder could be disposed symmetrically in the slipstream, there would be no lateral force on them. But, as you see in the diagram, the slipstream only affects the lower parts. If you could have more of the fin and rudder below the fuselage, you might achieve what you want, but the aeroplane has to sit up at an angle on the ground to get a big angle of incidence of the wings to help you to land slowly, so there is no room for extra fin and rudder below. You can see in the end view of the fin and rudder, the lower parts only are affected and catch the upper part of the slipstream which, as it rotates, exerts a lateral force on them, tending to turn the aeroplane round, just as if the rudder were put over; with engine on you have to counteract this force the whole time by ruddering against it. When the slipstream disappears, due, say, to engine failure, you no longer feel this force. This may also catch you unawares and make you swing the aeroplane the other way, because you have become accustomed to pressing with your foot on the rudder bar.

Therefore, if your engine fails you have to look out for two things: Firstly, the maintenance of your flying speed, to keep the lift equal to the weight; and secondly, the new conditions of balance of your aeroplane.

I have pointed out that in a given aeroplane you cannot fly level below a certain speed. This is frequently about 45 m.p.h. with an angle of incidence of about 15°. At this point your lift reaches its maximum, and with any increase of angle it will fall off. This is called the stalling angle, and at this angle a breakdown of the stable air flow round the planes takes place, your control surfaces become ineffective, and if the engine is cut out you have to lose height and regain speed before you can again control your aeroplane. If this happens close to the ground you may not regain control before you strike it and then you crash. Therefore it is essential that you should always keep your speed, say 10 per cent. above your stalling speed, when you are close to the ground. When I take a new type of aeroplane up, the first thing I do is to climb it to a safe

height and find out what its stalling speed is, in other words, how slowly I can safely fly it. One of the worst troubles of a stall is that lateral instability nearly always makes itself unpleasantly conspicuous. One wing may drop and the ailerons have no power to right the aeroplane; similarly, the rudder has no power to correct the aeroplane if it becomes slewed. The tendency is then for the aeroplane to drop its nose and get into a spin, of which I will say more later.

I have referred to the fact that the size of the aeroplane determines in a general way the order of magnitude of the control forces and that the stability characteristics affect the control forces in aeroplanes of the same size. The third factor which determines the magnitude of those forces is the speed. In a given aeroplane, at high speeds the controls feel relatively heavier, due to the increased air force; and as the speed goes down they feel lighter. When the speed drops to within ten or fifteen miles an hour of stalling speed the controls begin to feel sloppy, and as stalling speed is approached they become entirely useless. Aeroplanes are usually designed so that the controls feel most effective in the middle range of speeds; at high speeds they are more powerful, but they cannot be used so effectively, due to the force required to move them; at low speeds they are light and pleasant, but less effective. The same effect is noticeable when you lose way on a ship.

When do you fly near stalling speed; in other words, when do you have to be most careful? In getting off and landing. In getting off you open out your engine and commence to run along the ground. The slipstream will almost immediately give your elevators a little power, so you raise the tail slightly to decrease the air resistance of the aeroplane. The extent to which the tail is raised varies with individual pilots; theoretically the aeroplane should be kept at the angle of minimum drag, but in any case the tail should not be raised to a greater extent than will bring the longitudinal axis of the aeroplane parallel with the ground. As you run along you will constantly have to make movements of your control column to allow for the varying effect of the slipstream on the tail, which has been referred to; and you will have to counteract the turning tendency which will rapidly develop, due to the wash of the slipstream on the fin. As you are travelling at such a low speed you may need absolutely full rudder to do this. After a time you realise by the feel of the controls, that is, their effectiveness, that you have got up a greater speed than stalling speed and that you are nearly air borne. You can then gently lift the wheels clear of the ground by depressing the tail. It is as well to get up a speed at least 10 per cent. in excess of stalling speed before the wheels rise more than a foot or so from the ground, so as to leave yourself a good margin for controlling the aeroplane, especially laterally. We saw also that this will probably put you at your best climbing speed, which is somewhat in excess of the lowest speed at which you can fly. I do not say that this is the quickest way of getting off; the practice of pilots varies very much; but it is the safe and normal way.

Now for landing. The essence of landing is to stall your aeroplane at ground level. As the aeroplane sits on the ground the planes are considerably inclined, perhaps about in the stalling position. What you want to do is to approach the ground in a glide and flatten the aeroplane gently out, increasing the angle of incidence and decreasing the speed, until just as the aeroplane stalls, the wheels and tail skid touch the ground simultaneously, and the aeroplane runs along and gradually pulls up. When you glide in, you want to glide as slowly as you can, so as to stall as soon as possible after crossing the boundary of the aerodrome, and take up the least space in landing. But you dare not glide too near stalling speed, because your controls are not good enough; and if lateral instability develops you may drop a wing and have serious trouble. Therefore you glide in about 15 m.p.h. above stalling speed. At fifteen feet or so from the ground you gradually commence to flatten out with the elevator. This takes

some learning and you always pay for an error of judgment by some rather unpleasant bouncing. If you stall the aeroplane about four feet off the ground instead of at ground level, you drop heavily, and this is called "pancaking." If you do not flatten out soon enough, you fly into the ground and bounce, and make what I heard an American describe as a "low water landing with high tide." You always keep your engine running a little as you can damp bouncing by a judicious use of it. If your engine fails entirely in flight you simply have to make the best of it; and if you are compelled to land in a confined space, your success will mostly depend on how cleverly you judge your glide. There are many tricks by which pilots lose height, while yet keeping a margin of control when coming into an aerodrome, which I have not time to describe.

In the early days a spin was looked upon as an unfortunate event which terminated your career as a pilot; nowadays it is practised freely as a manœuvre, and is a rapid way of losing height, as long as you do not practise it too near the ground. Every pilot wants to experience spinning as he is then better equipped for regaining control if he spins by mistake. Why should he spin by mistake? We saw that the curved planes used to-day were not associated with inherent longitudinal balance; well, neither are they with lateral balance. If an aeroplane is badly stalled it becomes very unstable laterally when flying straight. The air forces on the wings are such that they tend to spin it over and over sideways, one wing going down and the other wing coming up. I will try and explain why.

When an aeroplane spins the average angle of the wings may be as much as 30° to the relative wind, although the aeroplane is nose down and losing height rapidly, owing to the wings lifting very inefficiently. And if, as you sit behind the wings looking steeply downwards, you are rotating clockwise in a right hand spin, the starboard wing is dropping relatively and the port wing is coming up. Therefore the starboard wing is increasing its angle to the relative wind steadily out to the tip, reaching say 50°, and the port wing is decreasing its angle down to, say 10° at the tip. Strange as it may seem, a curved wing may lift as much at 10° as it does at 50°, so there is no force tending either to increase or to decrease the speed of rotation; and you can see that this will be a steady condition of flight, in which the wings will continue to rotate on their own, that is to say, the aeroplane will go on spinning unless some violent disturbance is introduced to destroy this condition. When you are spinning you feel that there is some uncontrollable force tending to whirl you round and you cannot check it by the normal means. You may have given the rotary impulse with the rudder yourself after having stalled the aeroplane, or the aeroplane may have dropped a wing and started rotating on its own. This condition is known as autorotation, and can only exist when the average angle of the aeroplane is greater than its stalling angle. How are you to destroy it and recover from the spin? You have got to realise that you are well above the stalling angle and that you have got to unstall yourself. Because the nose of the aeroplane is pointing down the instinct is to pull the control column back to get the nose up; actually this makes things worse and keeps you stalled. Here then is a case where the requisite motion of the control mechanism is opposed to the observed motion of the aeroplane; that is, to get the nose up when stalled, you do not pull back the control column, but have to push it forward. So you push the control column forward, which has the effect of reducing the angle of incidence, bringing the wings back to below stalling angle and destroying the condition of autorotation, which can only occur when stalled. At the same time you assist in checking the rotary motion by applying opposite rudder. You then end in a dive, as the nose has all the time been pointing steeply down. From this dive you can gently pull the aeroplane out in the normal way. The best thing is so to fly that you do not induce accidental spinning; the next best thing is to understand how to recover in the minimum space, and this you do by studying individual types, the characteristics of their balance and of their wings.

I have said something about the rotation of an aeroplane in an abnormal way; I will now deal with turning in normal flight. Suppose you wish to turn to port. To produce this turn you have got to supply a force towards the centre of the circle you are going to turn about, and at the same time produce a couple to point the nose of the aeroplane always in the direction of flight as you go round the curve. You supply the force by banking or tilting the aeroplane with the port wing down and the starboard wing up; under these conditions the air force on the wings, instead of acting vertically upwards, is inclined towards the centre of the turn, thus drawing the aeroplane out of the straight path to a curved path. At the same time a couple is required on the aeroplane to swing it so that it points continually round the curve; this couple you supply by ruddering to port. For any rate of turn, that is to say, amount of bank, there is only one correct amount of rudder to give; if you give more you point the nose too much round and skid outwards; if you give less you slip inwards. A turn on an aeroplane is thus very similar to a turn on a bicycle; if you do not tilt over the correct amount you skid one way or the other. For steep banks, that is sharp turns, your elevator has to be called into play, and it takes some time to learn to co-ordinate the movements of your rudder, ailerons and elevator correctly.

I remember watching Hucks, in 1912 I think, the first Englishman to loop the loop, and thinking what a hair-raising spectacle it was; yet so has flying developed that it is now an everyday manœuvre. You fly the aeroplane at a fair speed, usually about 100 m.p.h. You then pull back the control column and impart an upward acceleration. As the aeroplane goes up vertically the propeller thrust is much less than the weight of the aeroplane and the speed falls off rapidly until, when you are upside down, it may have fallen to 50 m.p.h. The acceleration towards the centre of the loop presses you into your seat, and in a good loop you never tend to fall out. If you pull the aeroplane over violently, you stress it very heavily and you could actually break a very manœuvrable aeroplane in this way. The feel of apparent gravity, referred to before, is a help to you, as it gives you a warning as to how heavily you are stressing the aeroplane. During the whole loop you keep the control column back, and if you arrange your initial speed rightly and pull over correctly—you have a fairly good latitude of error—the aeroplane comes round again to normal flight. The engine is usually throttled down during the last part of the loop to avoid losing any more height than you can help when the aeroplane is pointing vertically downwards.

The roll, I think, is the prettiest manœuvre I know. The French discovered it before we did. British pilots practised it early in 1917, about the same time as voluntary spins. The aeroplane is rolled round sideways and the motion shows the same characteristics as a spin, with the difference that the fuselage of the aeroplane is kept roughly parallel with the ground. I am convinced that the phenomena of autorotation are involved and that the wings are in some sense stalled. The aeroplane certainly seems to take charge momentarily as it does in a sustained manner for a spin.

You have to set up the rotary motion with a violent impulse from the rudder and hold the aeroplane stalled with the elevators.

I am afraid I have not time to deal with more advanced manœuvres still, such as rolling off the top of a loop and inverted flight, all of which are fascinating to the student of the art of flying.

These manœuvres are most easily performed in small highly controllable aeroplanes. Controllability on large aeroplanes is wanted mainly for safety, so that you have the largest margin of control when your balance is upset and large disturbing forces come into play. Take a four-engined Handley Page, weighing fourteen tons. Its area is approximately 3,000 square feet, and it is controlled by hand. Larger aeroplanes still will be constructed and the magnitude of the control forces will almost certainly overtax the strength of the pilot. We are

therefore experimenting with relay control devices to take the major proportion of the weight off the pilot's hand, while leaving him the feel.

For the success of civil aviation we have got to fix the word "safety" continually before our eyes. If the pilot really appreciates the characteristics of his aeroplane at and near stalling point, the manner in which variation of engine power affects his balance and the way he can get the most out of his control surfaces, he will then be well armed when he suddenly finds himself face to face with situations of difficulty and danger. I hope I shall never forget the maxim of my first flying instructor: "Keep your head and your flying speed!"

Throughout these lectures I have insistently dwelt on the difficulties and dangers in the art of flying. The study of an art largely consists in measuring its difficulties in the most rigidly critical spirit.

In order to see how well these difficulties have been met and what little risk there now remains, it is only necessary to turn to the statistics of accidents in civil aviation of to-day. The number of miles flown for every accident is something like 35,000 or nearly one and a half times round the world. The British public never minds facing a risk, and I make bold to say that the risk will be faced all the more cheerfully if it is calmly reviewed and its measure clearly grasped.

As we look forward into the future, imagination may reveal to us the steady march of science. Fifty years have passed and the lonely airways over the middle Atlantic are filled with traffic as the great air liners pass and repass at their appointed levels. At 3,000 feet the heavy tramps; at 5,000 feet the slim silver grey liners; at 10,000 feet the international patrol with a double ensign fluttering at the leader's tail. The sky will throb with the soft whir of silenced engines. The flying hours of a long summer's day will measure the distance from the Statue of Liberty to the dome of St. Paul's.

I will close my lecture with a tribute to Wilbur Wright. I feel that he did more for the development of aviation than any other one man. He was his own designer and his own pilot. Inspired as he was by his faith in the ultimate future of aviation, he was a model of experimental genius and of sheer physical courage. Disease took him from the world in the flood tide of his achievement, but his memory will remain undimmed in the hearts of those to whom he bequeathed the kingdom of the air.

CORRESPONDENCE.

To the Editor of the AERONAUTICAL JOURNAL.

SIR,—I have found Lieutenant-Colonel H. W. S. Outram's lecture on "Ground Engineering" very interesting. Since he invites constructive criticism I venture to send you my views.

To begin with, the name "Ground Engineer" seems to me neither handy nor happy. "Test Engineer" would be better. Clipped short to "Tester" it would, at least, convey some idea of the fellow's duties. And being similar to "Test Pilot" would suggest that he might occasionally take the air instead of implying that he should never venture off the ground in one of the machines for which he is responsible.

There is to be one ground engineer to an aerodrome it seems. And he is to sign a daily certificate in respect of each passenger-carrying aircraft which flies from his aerodrome on any day. By his certificate of airworthiness the ground engineer has to pledge himself that the craft "is fit in every way for the flight proposed."

Too great a burden of responsibility is laid on the ground engineer. "Fit in every way" involves the solution of complicated questions of fact and opinion. An aeroplane is a structure fitted with an engine. Its fitness for a journey depends on the due design, proper construction, and skilful maintenance of the component parts of both structure and engine. But it also depends on the suitability of engine to structure, on the proper installation of the engine in the structure, on the due distribution of fuel, cargo, passengers and pilots; on the due provision of petrol and oil, and of instruments and accessories and on a thousand and one other matters of fact and subjects of opinion. No single ground engineer on a busy aerodrome (when aerodromes get busy) will have either the time or the ability to give proper attention to all of these matters. But he will be compelled nevertheless as each craft takes the air to certify it "airworthy." In practice the impossibility will be achieved by some form of delegation. A good ground engineer will rely on the engine mechanic for the running of the engine and on the rigger mechanic for the condition of the machine, devoting his own energies to general supervision and the resolution of problems of policy, opinion and doubt. The bad ground engineer will leave practically the whole of his job to the mechanics and reserve his own energies for the task of shifting the responsibility for accidents on to some one other than himself.

From Colonel Outram's Paper it appears that prospective ground engineers can be grouped in two classes and in three ways:—

CLASS I.—Woodworkers, riggers, aerodrome workers.

CLASS II.—Metal-workers, fitters, shops workers.

But at each aerodrome there is not to be more than one ground engineer, who will only be really an expert in one of these six ways. He will always be less expert in at least some of the other five than the mechanic whose trade it is and whose work it will be his duty to certify and supervise. A bad state of affairs.

What possible alternative is there? One ground engineer is an expense, two would be an extravagance and six an impossibility.

The answer is that the profession of test engineer, like every other profession, must be graded with regard to qualifications, ability and pay. The lowest grade will be mere mechanics, do mechanic's work and receive mechanic's pay. The higher grade will be engineers in fact as well as in name, and will be paid as engineers and do engineers' work.

Test engineers of all grades will be paid by the company which employs them, to whom they will also be responsible for the maintenance and safety of the machines. The lower grades will work on the machines with their own hands.

But what about the certificate of airworthiness? Which of the grades is to be legally qualified to sign it? And how will the grading enable the certifier to be equally expert with regard to construction and maintenance, engine and machine, woodwork and metalwork?

Here again I think that the development of the subject is not proceeding along quite the right lines. There is a confusion of thought involved in the requirement that the ground engineer shall certify that the aircraft is fit in every way for the flight proposed. Airworthiness is a composite quality made up of facts and of opinions. The revolutions to be got from the engine are a matter of fact, and reducible to definite figures. The safest position for the petrol tank, the provision of life-buoys for passengers on sea trips and similar problems are a matter of opinion to be decided by experts. Matters of fact can properly be classified in tables and certified by mere mechanics. Matters of opinion are not reducible to figures and must be left to be certified in general terms by the trained and qualified engineer.

My proposal is therefore this :—

Instead of a single certificate of airworthiness made out for each machine every day by the sole ground engineer I would substitute—

(*a*) A formal certificate of airworthiness to be signed by a senior tester in respect of each machine at regular intervals; which might, perhaps, be based on the flying hours of the machine. The certificate will state that having inspected the log books and the machine he is of opinion that the machine is airworthy, either "in every way" or for such and such a flight, or with such and such qualifications, or subject to such and such precautions being taken or extra fittings being added.

(*b*) Informal log book certificates in respect of each flight (or each flying hour in a case where a series of short flights is being made); these will be signed by junior testers on stock forms, and will certify *facts* not *opinions*.

Suppose now that an accident happens and it becomes necessary to allocate responsibility. The present airworthiness certificate is of little, if any, legal value. The oath of the ground engineer that he found the craft airworthy would shift the burden of proof on to those who denied it. But the piece of paper which certified this would not, as a rule, be admissible as evidence at all. This should be changed. The certificate of a senior tester (holding an Air Ministry licence at the time) should be made admissible in any court as *prima facie* evidence of the airworthiness of the craft according to the tenour of the certificate. Similarly the certificate of either a senior or a junior tester of any fact relating to the airworthiness of a craft should be admissible as *prima facie* evidence of the fact so certified. False certification would have to be made an offence, and

the putting in of a certificate would entitle the other side to give notice to cross-examine. The certificate of a tester who was dead, or for other good reason could not be called as a witness, would be admissible *de bene esse,* but would not operate by itself to shift the burden of proof.

Reverting to the subject of the test staff at an aerodrome, it will be seen that my proposal involves :—

(i) A senior tester in charge. He is a junior tester who has risen through having acquired an expert knowledge of the shops and the aerodrome, of the trades of rigging and of fitting and woodwork and metalwork. He has shown that he has ability and can inspect as well as test. He gets an engineer's pay.

(ii) Junior testers of varying experience and ability. They start as mechanics. Some in the shops and some on the aerodrome. Some are experts in wood, others in metal; some riggers, some fitters; some will rise, others not. They work on the machines and get mechanic's pay of varying amounts.

Set over the testers are the Air Ministry inspectors. They are relatively few in number, are not attached to any aerodrome and were previously testers themselves. They are chiefly concerned with licensing, supervision and the investigation of accidents. They do not sign certificates.

P. T. CARDEN.

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All communications should be addressed to the Editor.

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Notices of the Royal Aëronautical Society.

Election of Members.

The following members were elected at a Council Meeting held on June 21st:—

Associate Fellow.—Captain L. H. Mander, F.R.G.S.
Student.—C. H. R. King.
Member.—Captain the Right Hon. F. E. Guest, C.B.E., D.S.O., M.P.
Foreign Members.—Lieut. Esteban R. Zanni, Lieut. Cmdr. G. Hara, I.J.N.

It is regretted that the announcement of the election of Mr. Donald Smith as an Associate Member of the Scottish Branch was omitted from the June announcements.

Election of Chairman.

Lieut.-Col. Mervyn O'Gorman, C.B., F.R.Aë.S., was declared duly elected Chairman-elect at the Council Meeting, held on June 21st. He will assume office on October 1st, when Air Commodore H. R. M. Brooke-Popham, C.B., C.M.G., D.S.O., A.F.C., the present Chairman, becomes Vice-Chairman.

Admission of Associate Fellows.

In order to carry into effect the new regulations for the admission of Associate Fellows adopted at the Annual General Meeting, the Candidates' Committee has been engaged upon drawing up a syllabus for the Society's examinations, which will be published in full in a forthcoming issue of the Journal, it now having been adopted by the Council. The syllabus provides for candidates' examination in the following subjects:—

PART I.
(*a*) English.
(*b*) French, German, Italian, or Spanish.

PART II.—One paper in any two of the following subjects, to be selected by the candidate.
(*a*) Strength and Elasticity of Materials, and Theory of Structures.
(*b*) Aerodynamics.

(c) Heat Engines.
(d) Meteorology and Navigation.
(e) Mathematics.
(f) Chemistry and Metallurgy.

The Council have decided that, for the present, each paper will contain a large number of questions in order to give a wide choice of tests of the candidate's knowledge.

The Council have further decided to accept an approved course of aeronautics at a University or Technical College as part of the two years' qualifying experience in the application of the science of aeronautics—required by the regulations in addition to examination results—the total allowance in such cases not to exceed one year.

Details of qualifications giving exemption from either Part I. or Part II. of the examination will be found in Clause IX. of the Regulations.

The first examination will be held in April, 1922.

A list of books recommended for Students has been drawn up, of which copies may be obtained on application to the Secretary.

Summer Vacation.

Members are notified that the Offices of the Society, including the Library, will be closed for annual cleaning from Saturday, July 30th, to Monday, August 8th.

W. Lockwood Marsh, *Secretary*.

PROCEEDINGS.

TENTH MEETING, 56th SESSION.

The Tenth Meeting of the 56th Session took place in the Hall of the Royal Society of Arts, London, on Thursday, March 3rd, 1921, Air Commodore E. M. Maitland presiding.

The CHAIRMAN introduced Major T. Orde Lees by saying that he was a remarkable man of restless energy and that he loved a spice of adventure. No sooner had he come back from his South Pole expedition with Sir Ernest Shackleton in 1915 than he set about joining up in the Air Force as a pilot. They said they could not take him on as a pilot because he was too old. He then set about saving the lives of aeroplane pilots by parachutes, and had devoted himself to that cause ever since. At first he could not get an aeroplane on which to commence his experiments, and he had to lead off by jumping off the top of the Tower Bridge, 153ft. in height, which successfully demonstrated that the type of parachute he used was a very quick opening one. From that time onwards he had been assiduously throwing himself out of every form of aeroplane and from kite balloons, and also studying the problems of parachutes. He thought that he was right in saying Major Orde Lees had done more practical parachuting from aeroplanes than anybody else in this country except Miss Boyden.

Major T. ORDE LEES then delivered the following lecture:—

SAVING LIFE IN AIR WRECKS.

When the aeroplane came into being ten years ago the parachute had no place in the practical politics of aeronautics.

The extensive use of observation balloons, throughout the war, brought the life-saving capabilities of the parachute to the front.

In pre-war days the parachute was regarded almost exclusively as a medium for daring displays.

Public interest has been aroused by the fact that the lives of over 800 men were saved from balloons by parachute and many more might have been saved from aeroplanes by the provision of this simple appliance.

For the last six months of the war the Germans were using a comparatively crude type of parachute in nearly all their aeroplanes. This equipment was entirely optional. Nine out of ten pilots elected to carry them. According to the best information I can get, of the pilots who had occasion to use them, nine out of ten saved their lives.

I was in Berlin in November last and had long personal talks with five independent German pilots. Making every allowance for patriotic exaggeration on the part of my German informants, one must concede, from the reports of our own airmen, that at least five out of ten German pilots who resorted to their parachutes were saved. If only one in ten had been saved, the carrying of parachutes becomes both a humane and a man-economising proposition.

One of the biggest objections to the fitting of parachutes—their effect on that elusive quality of a machine termed " the performance "—seems to have been quite disregarded by the Germans. All war fliers appreciated the critical value of superiority of speed and climb. The weight of a 28lb. parachute makes an

appreciable difference, two parachutes a material difference on a D.H.4 for instance. One parachute reduces the speed by $1\frac{1}{2}$ per cent., two by nearly 2 per cent. The climb is reduced 50 feet and 75 feet per minute respectively. A large passenger machine fully equipped would probably be less affected.

The fear that aviators might be tempted to resort to their parachutes prematurely when, by sticking to their aeroplane, they might succeed in saving it seems to have had no foundation in fact amongst the German fliers. From what I know of British fliers I think it would have less amongst them. Still, the suggestion has been advanced as an argument against fitting parachutes.

During the war I estimate that about 200 British pilots were seen to jump without parachutes from their burning machines at high altitudes rather than be roasted to death in mid-air. All were killed. Nearly all would have been saved if they had had parachutes, because they all proved that they were able to get out and jump and because a burning machine can be kept on an even keel until the last minute.

It has often been said that parachutes will act with certainty only when the machine is on an even keel and conversely that when the machine is on an even keel they would never be required. Well, there are about 200 cases where the doomed aviators demonstrated that they could make good their exits. Everyone in the Air Force knows of several cases of this happening, if they have not actually seen it with their own eyes. Two hundred is merely an estimate, but I can quote chapter and verse for three cases, two in war and one in peace, which must convince the most sceptical that the provision of parachutes would have saved the lives of two men whose great experience and ability in the air made them of real value to their respective countries.

The first is Major Lufberry—the American fighting Ace. Enemy action ignited his machine at 2,500 feet. For 2,000 feet he struggled to extinguish the flames and keep the machine under control. At 500 feet, unable to withstand the torturing heat any longer, he was seen deliberately to get out of his machine and jump to earth.

Lieutenant Berkeley, of the Coldstream Guards, was one of the very few British pilots who had ever made a parachute descent from an aeroplane. He did so in October, 1918. Three months later, in my presence, he collided in the air. The other machine, a single-seater, got away and made a lucky landing without an under-carriage.

Lieutenant Berkeley had a passenger. If both had had parachutes, both could easily have used them as the collision happened at over 2,000 feet. The right wing of the two-seater was badly broken. The machine was out of control all the way down, swerving this way and that but, for appreciable periods, righting itself and giving ample opportunities for the aviators to use parachutes. They had none. The pilot was killed, the passenger survived in spite of serious injuries. On this occasion fire did not break out on impact with the ground, as it so often does.

The third case is that of Peter Leigh. His machine burst into flames at only 200 feet above the houses at Finchley. He at once got out, apparently misjudged his height, and attempting to use his coat as a parachute, jumped. Successful parachute jumps have been made from less than this height. Peter Leigh clearly showed his ability to use a parachute even at a low height. He was killed.

To mention but a few amongst famous aviators who met their deaths in accidents where parachutes might have spared them, we have Lieutenant Warnford, V.C., Captain Ball, V.C., Pégoud, Cody, Professor Hopkinson and Major Gooden, the popular Farnborough test pilot, who had made a number of parachute descents from balloons before the war. He was killed by a wing breaking off in mid-air.

Whilst parachutes could have been used in thousands of cases during and since the war, it must be admitted that the majority of air casualties are due to accidents happening on or near the ground when taking-off or landing, collisions with terrestrial objects in fogs, or through engine failures and by stalling. There have been a great many accidents where no type of parachute at present on the market could have availed the aviators. No existing parachute would have saved Sir John Alcock or Major McCudden, V.C., for example.

It is quite a mistake to suppose that parachutes cannot be used with the machine in any position. They can be so used. The Germans so used them.

What is good for military machines in the matter of life-saving equipment should surely be as useful on passenger aircraft.

So far parachutes have not been made compulsory on any form of civilian aircraft. Until compelled by legislation aerial transport companies are not likely to reduce their useful carrying capacity by the voluntary provision of parachutes. Commercial always over-ride humane considerations until Parliament acts. If aerial transportation could be carried out at about half the cost of railway transport, parachutes would, no doubt, be fitted at once as a commendable refinement to every civil machine, if only on account of the attractive reduction in personal premiums already offered by certain insurance companies where parachutes form part of the equipment.

As soon as insurance companies are convinced that parachutes are a reliable means of life-saving, reduction of premiums should go far towards cost of parachutes. "Wheels and Wings" already quotes a substantial rebate if parachutes are fitted.

At present, seeking for plausible objections, but possibly prompted by motives of economy, it is not infrequently argued that the provision of parachutes would unduly emphasise the potential danger of flying, scare the public and reduce the passenger list—in short, the dividends.

The argument that, in large machines, passengers could not get out in time is as much of an argument against the use of large machines as it is against parachutes, but in any case, the statement is one that cannot be substantiated in the present state of our meagre knowledge on the subject. The other argument that "we will wait and see how they answer on military machines before adopting them on civil aircraft" is, like most "wait and see" arguments, fatuous because, in the first place, the price of procrastination may be hundreds of lives and much public confidence lost where parachutes could have prevented these catastrophes. Secondly, there is no need to "wait and see," for the Germans have already conclusively demonstrated the practicability of the aeroplane parachute.

If we "wait and see" much longer we shall wait long enough to see an aerial "Titanic" disaster. The public, who know nothing of aviation and care less at present, will suddenly wake up to the fact that something should be done to make it safer than it is; through the Press they will learn of the parachute and clamour for it.

The recent disaster to the Centaur Triplane at Hayes, where all six occupants were killed, is a clear case of an accident to a multi-passenger machine where all might have been saved by parachutes. The death at Huntingdon of Captain Sadler, who had often dropped parachutists from his machine, is another recent case where parachutes were urgently needed.

The Handley-Page crash at Golder's Green, a week before Christmas, was a case where the ordinary types of parachutes would have been useless, but no argument against fitting them, whilst the loss of another Handley Page in the Irish Sea during the same week was a potent argument for the policy of equipping trans-oceanic machines with parachutes-cum-lifebelts.

The problem of getting all the occupants out of multi-passenger machines is a very difficult one, but is receiving adequate attention.

Probably the most effective solution at present beyond the paper stage is the individual parachute carried on the passenger's back, but attempts to solve the difficult problem of removing the passengers and cabin *en bloc* seem hopeful.

One inventor, regardless of centres of gravity and pressure, seeks to relegate the passengers to the tail of the machine, which member, like that of certain snakes, can be detached at will and be left behind suspended in the air by a great parachute whilst the engine, wings, and, presumably, the pilot continue their headlong career earthwards.

This contraption reminds us somewhat of the desperate expedients of inventors to produce a folding bicycle. The patent records, especially those of the American office, abound with crude ideas for salving a part or the entire aeroplane by means of a parachute shown generally in the accompanying drawings as of hopelessly inadequate size. Strange to say, of the three or four hundred patents I have examined the vast majority show parachutes so small that the speed of descent would be fatal, and with a single exception, not one of all those patents shows the parachute in flight correctly shaped.

In both practice and theory the suspension cords of a parachute must be at a tangent to the surface of the umbrella portion at their points of attachment to its periphery whilst the parachute is in flight. One would have thought this was obvious, but in not a single drawing I have ever seen has it been shown absolutely correct, which only shows how little of the theory the people who rush into patents really know. This may also account for the enormous number of inadequate parachutes proposed, not to mention the ludicrous attempts to combine parachutes with the aviator's clothing.

It would be very convenient if a parachute the size of an umbrella would reduce one's downward speed to safe limits. Unfortunately, the minimum size of parachute to produce a landing at safe speed under any conditions seems to be about 28ft. diameter, which accounts for one of the principal difficulties in the parachute problem.

In the American patent files there are at least a dozen showing a parachute about three feet across for saving a man. Equally quaint are some of the parachutes shown as salving the whole aeroplane. These vary in the specifications from 10 to 20 feet in diameter and are invariably shown vertically above the centre of gravity of the machine, with the latter horizontal just as if it had no forward speed. To salve a super Handley a parachute the size of Trafalgar Square, weighing a ton or more, would be required.

The first authentic reference to parachutes as they are known to-day is to be found in the aeronautical sketch book of Leonardo da Vinci (A.D. 1500). His prevision was extraordinary. He outlines a parachute almost identical in size and construction with those used for man-saving during the war.

He does not seem to have known quite how it might be used, but as flying was always regarded as inherently dangerous until it was actually achieved in 1908, early investigators often thought more of the cure than the prevention of accidents and Da Vinci was an inventor of flying machines—orthopters.

As to actual descents, there are perfectly credited records of such having been made from a tower in the 18th century by Fauste Veranzio, using a cloth stretched on a rectangular framework. Another experimenter, Gaspard Le Norman, undoubtedly made descents with something of the same kind in 1783. Montgolfier also made a couple of descents.

In 1793 Blanchard, the well known pioneer balloonist, after trying experiments with his dog, himself made a drop at Basle. He seems to have blundered in some way, probably losing his head and dropping almost as soon as the balloon commenced to rise, so that the parachute was not fully open. Anyhow Blanchard broke one of his legs.

Garnerin, Blanchard's rival, followed suit immediately and with greater success. He made many drops in various countries and one of 8,000 feet in London, landing at St. Pancras.

His sister was the first woman to make parachute descents. She made about 40. In 1804 Kuparento, a Pole, succeeded in saving his life by using a parachute. A good many aeronauts lost their lives by neglecting to equip their balloons with parachutes.

Blanchard and Garnerin had several emulators. The parachute established itself as a medium for sensational performances rather than as an aerial life-saving appliance. The reverse is the case to-day.

Except for the universal adoption of the vent hole suggested by the great French astronomer Lalande, as a palliative to stop the violent swinging to which the early parachutes were prone, nothing of importance occurred until 1837 when Mr. Cocking killed himself by testing his huge inverted cone type of parachute. It weighed over 400lbs. and was forty feet in diameter at the top and eight feet at the bottom. The periphery was stiffened with a tubular tin hoop, the collapse of which, a few seconds after the start, was responsible for the fatality.

In any case so monstrous a machine was quite unpractical except as a spectacular apparatus. It acted as a drag on the Great Nassau balloon when it ascended. The sudden release of so great a weight caused the balloon to bound up many thousands of feet. The discharge of gas from the neck nearly asphyxiated the occupants.

Cocking's misadventure, although without practical, other than negative, value, is the most interesting parachute experiment as it was made with a theoretically efficient type. The collapse was due merely to bad workmanship.

Wise, a really splendid American aeronaut, demonstrated the possibility of such parachutes, not with himself but with his dog, as was the custom amongst the early aeronauts. Wise was not, however, lacking in daring for he invented the thrilling stunt of ripping his balloon in mid-air and allowing it to act as a parachute by reason of the envelope collapsing parachute-wise into the net. This can practically always be relied upon to occur when a spherical balloon bursts, provided there is sufficient height and that the neck line is not secured, or if secured can be untied.

When his balloon burst at 1,000 feet shortly after an ascent from Vauxhall Gardens in 1847, Green, a celebrated aeronaut, saved the lives of his four fellow passengers by his presence of mind in untying the neck line.

Captain Dale, at the Crystal Palace in 1892, was less successful, but then his balloon was at only 600 feet; some of you will remember the event. The two other occupants, one his son, survived.

A somewhat similar but safer expedient is to provide the balloon with a valance around its middle and to suspend the car from the periphery of this flounce. This is known as an equatorial parachute. It is a very old idea, having been suggested by Bramicki in 1867, whilst old cuts show it on Blanchard's balloon in 1784.

Why such a simple safeguard has not found greater favour I do not know, unless it is that bursting is considered too rare to need a remedy.

Dozens of patents exist for making flying machines which incorporate the parachute principle.

To many minds it seems that a descending parachute so nearly floats that it would not take much to make it do so. The fallacy is probably merely an optical and psychological illusion. Having no immediate background by which to gauge the speed of a descending parachute, the spectator, in spite of data to the contrary, often goes away with the impression that the man-carrying parachute floats on the air as lightly as its vegetable prototype, the parachute seed of the common dandelion.

The inventive but unscientific observer proceeds to work out a scheme for making the parachute fly, claiming, with pride, that the passenger can laugh at derangements of the flying gear.

Some, realising the futility of making a parachute fly, have contented themselves with taking advantage of its descent to manipulate subsidiary flying gear or to test manual orthopters.

The two most widely known experimenters of this type of machine were De Groof, who dropped from a balloon at Chelsea where he fell 5,000 feet and was killed owing to his wings folding over his head, and La Tour, who actually had flapped about a bit, but was killed at Lee Marshes through sheer bad luck. His apparatus was suspended below a balloon. It seems that the aeronaut lost his head and acted too late for the flying machine to clear some trees. He immediately afterwards tried to land. La Tour was mortally injured by being dragged. He was French and spoke no English, while the aeronaut spoke no French. No interpreter was in the balloon, so co-operation was at a discount.

The parachute is incompatible with the aerofoil as such. Many unscientific people cannot understand why it is that aeroplane wings do not act, or cannot be made to act, as parachutes when a machine falls or stalls.

Well, they do sometimes, but owing to the immense weight in proportion to wing area—as much as 10lbs. to the square foot in modern machines—the speed of descent would be fatal.

A life-saving parachute, 28 feet in diameter, carries half a pound per square foot for an average man of 160lbs. when opened to a diameter of 20ft. This gives a speed of descent of 16 feet per second, 1,000 feet per minute, or approximately 12 miles per hour. A parachute attains its terminal velocity within a second after opening. The momentum of the load is very rapidly absorbed. Any increase in the load or decrease in the area increases the speed. The resistance varies inversely as the square of the speed so that fortunately stout parachutists will find that the normal size life-saving parachute will not bring them down much faster than their lighter brethren.

Owing to her girl companion fainting when about to do a double descent from a balloon, Miss Dolly Sheppard, a pre-war professional parachutist, courageously seized her in her arms and brought her down on her parachute without fatal, though considerable, injuries.

On two occasions during the war, two officers have accidentally descended from their balloons on a single one-man parachute. On one of these occasions the burst balloon as well came down with the two officers on the one parachute. Lieutenants Pape and Jardine, the two observers in question, were somewhat badly injured on landing.

The original Bleriot aeroplanes were so lightly constructed, on account of their tiny 25 h.p. Anzani engines, that there are one or two cases on record where they pancaked down from considerable heights in true parachute fashion and without serious damage to pilot or machine; but these cases are rare owing to the centre of gravity and centre of lift not coinciding.

Thirty feet per second, double ordinary parachute speed, is generally con-

sidered to be the limit of speed at which a human being could strike the earth without serious harm. That is equivalent to jumping off a wall 14 feet high.

For descents on to hard ground the minimum diameter for a parachute as cut at present should be 28 feet. In flight the "fluting" of the periphery reduces the diameter to about 18 to 20 feet, according to the weight of the load.

G. I. Taylor, the mathematician, has designed a wonderful parachute which comes down at its designed diameter without "fluting."

Mr. Herbert Spencer has used a parachute of only sixteen feet in diameter. None but a very experienced parachutist could survive repeatedly the speed at which a 16-foot parachute must descend. A descent into water from any height might be made with impunity with a parachute of only 10 to 12 feet.

For use on all aircraft having a speed of their own and on captive balloons which have, of course, a relative air speed, due to the wind, it is necessary to pack the parachute in some form of container. On free balloons, owing to the fact that there is no relative air speed, the parachute may be hung fully extended in length from the equator of the balloon. This is the usual practice amongst professional parachutists.

The first attempt to pack parachutes was the Spencer "C" type case, evolved at the instigation of Air Commodore Maitland. It was used with success throughout the war on all kite-balloons and on some airships. Owing to the likelihood of the parachute being blown out of this case before the aviator has dropped the full length of the parachute, and the tendency, therefore, for the slack silk of the parachute to get foul of the aeroplane and tear or tangle, the Spencer "C" case is not suitable for use on aeroplanes.

When it was decided, two months before the end of the war, to equip aeroplanes with parachutes, the only one on the market in large quantities was the Guardian Angel A.1 type. There are fifteen types of Guardian Angel parachutes, of which the A.1 and several others are extracted, by the weight of the falling aviator, from cases pendant from the aeroplanes.

The packing is elaborate and takes two or three hours, but as they are issued from the factory ready for use and need no repacking for a couple of years or more, whilst a Spencer and most other parachutes require repacking weekly, this is not a serious objection.

It is disputed by many persons that parachutes of this normal type (termed by Colonel Holt anchored parachutes) are capable of being used when the machine is out of control.

It is often objected that parachutes must foul the machine in a spin. This is not necessarily the case at all. The smallest machines take at least three seconds to make a complete turn when spinning. In three seconds the parachutist is already over a hundred feet below the point in the air from which he started.

If the suspension cord of a normal type parachute container is made sufficiently long, as suggested by Major Mostyn, the container is clear of the machine before the parachute is extracted, whatever the position of the aeroplane may be.

If the suspension cord is long enough it is immaterial whether the aeroplane winds it round the fuselage half a turn or so during the spin.

The propeller is a possible danger, of course, but it is that on the ground if you try to stop it with your head. If the suspension cord gets foul on the propeller it must be instantly severed, but such an occurrence will be rare and no one claims that parachutes will save cent. per cent. of men who use them any more than lifebelts and lifeboats do.

In certain cases the knapsack type parachute (such as the Autochute, Floyd-

Smith and Mears, to mention three prominent systems of this type) may be less prone to fouling the aeroplane, but there is nothing to prove it yet. So far the claims of their inventors rest on conjecture, except perhaps the Mears, which is closely allied to the German Heinecke parachute, the one that has made over 500 drops from aeroplanes on active service.

It is well known that the anchored type of aeroplane parachute has been ripped on the tail skid on two or three occasions. This is due merely to the fact that the suspension cord was too short. If the suspension cord is made long enough the case must be clear of the tail before the parachute is extracted from it. The only reason why this is not done on demonstration work is that it increases the length of free fall. All demonstrators naturally like to reduce this as much as possible.

An efficient shock absorber must be introduced into this line or the kinetic energy of the container, when it comes to the end of the supporting line, might cause the line to break.

It is claimed by other inventors that the parachute stowed in a knapsack on the aviator's back and extracted therefrom when the latter jumps, either by means of a line attached to the aeroplane, as in the Mears and German Heinecke parachutes, or by the miniature pilot parachute, as in the well known Autochute, Floyd-Smith and Broadwick systems, is far less likely to foul the aeroplane than the original anchored type of parachute. Others contend that the pilot parachute is just as likely to be carried by the slipstream into the tail unless operated intelligently (but who ever heard of panic-stricken passengers acting intelligently?)

In spite of the natural objection of pilots to be saddled with a 16lb. knapsack, this type has found a good deal of favour in America.

In quite a number of the American patterns the aviator is required to jump headlong into space and deliberately liberate the parachute by means of pulling a ring or handle on his chest when he considers that he is well clear of the machine.

This particular method of operation does not seem at all suitable for passenger work, as the passengers, if they could be persuaded to jump at all, might either liberate the parachute prematurely in their embarrassment and so cause it to foul the machine, or might fail to operate it altogether.

The pilot parachute idea is sound so long as it is not left to the aviator to extract or release the pilot parachute himself. This must and easily can be done automatically, and not until the aviator is well clear of the machine.

The Mears is a simple and excellent proposition and for multi-passenger machines the best existing solution, because the passengers can quit in any order, through any exit, having nothing to do but jump, and because the operating attachments left behind on the machine cannot possibly foul the passengers who jump last. It also has the advantage that its extraction from its knapsack case can be delayed until the passenger is radially clear of the machine.

In principle it is merely rolled up in the knapsack from which it is extracted and unrolled by a long flat strip which is attached by one end to the aeroplane and rolled up, as to the other end, with the parachute.

It is these strips which, after the passengers have jumped, remain attached to the machine and blow harmlessly to the rear.

There is one other kind of aeroplane parachute, the extraction type, often termed soaring parachutes, though the impossibility of a parachute actually soaring over a fast moving aeroplane must be apparent to everyone.

The idea is quite ideal and in spite of what has just been said is not absolutely impossible. The attention of inventors should be concentrated on this difficult problem.

Experiment alone can prove whether the parachute thrown up above the machine would exert a pull sufficient to lift the aviator from his seat, before the axis of the parachute, and consequently its pull, was in line with or parallel with the line of flight of the machine.

As the line of flight forms so small an angle with the axis of the fuselage in modern machines the successful operation of the extracting parachute can be decided only by practical tests.

In any case the parachute, however it may be projected above the machine, must lose its forward momentum almost simultaneously with the commencement of its development. Before it is fully open it is bound to travel rearward through an arc having the parachute's point of attachment to the machine or aviator as its centre. It is doubtful whether it can develop sufficiently to exert a pull strong enough to extract the aviator from his seat until it has the pull in a direction which imperils the aviator by collision with the tail of the machine, especially the stabilising fin and rudder.

If a machine is stalling or falling its axis may be at a sufficient angle to the line of flight to obviate the danger of decapitation by the rudder, etc.

Whether the aviator could survive the shock of being whisked out of the machine is a little problematical. In the normal type parachute the strain of having one's momentum arrested, even after a fall of several hundred feet, involving a speed of 95 m.p.h. after a fall of 300ft. or more, is almost negligible. There seems therefore no reason why the actual act of extraction should in itself prove fatal. At the same time it does not matter whether the aviator is dragged out of the machine in his seat or by means of body harness, the strain of his transmission ultimately falls upon him.

It may be that the cone of air set up by the slipstream would cause the parachute to the function at an angle of 10 degrees or so to the axis of the machine, and it may be that the steeper the machine was diving the more the action of this type of parachute would be favoured. Rollers on the back of the occupant's seat to lift him, seat and all, with an initial trajectory sufficient to clear the empenage have been suggested by Haydn amongst others.

Pégoud did actually succeed in getting clear from a 25 h.p. Bleriot machine single-handed with a parachute of this kind invented by a canteen keeper called Bonnet. It was operated by means of a pilot parachute. It is interesting to note that the first drop ever made from an aeroplane in Europe was operated by the pilot-parachute system. Pégoud's machine, continuing on a mad career by itself, looped the loop, which suggested to him the possibility of his doing likewise. It finally landed almost intact.

A third essay by Pégoud's pupils Lemoine and Bourhis for a fee of £1,000 at Vienna nearly proved fatal. Everything went wrong. Part of the metal sheath which covered the parachute fouled and damaged the empanage and elevators. Lemoine, the pilot, crashed and was in hospital for three months, whilst Le Bourhis, the parachutist, came down at almost fatal speed on half a parachute and broke his leg.

The very first man to drop from an aeroplane by parachute was an American named Berry at St. Louis in America, just 12 months in advance of Pégoud; the first man in England, Professor Newall, the first woman, Miss Broadwick, in America, and Miss Sylva Boyden in England, who has since done much to prove that parachuting is not dangerous.

The path taken by a parachute is rather interesting. Instinctively one thinks that a parachute drawn out from a container below a flying aeroplane will describe a rearward and downward path in a straight line at an angle of about 45 degrees to the aeroplane. A little further consideration confirmed by photographs shows that the exact opposite is the case.

Parachutes do not conveniently slow up like lifts on reaching the ground. The landing is often much more severe than is generally supposed, especially in a high wind, as the parachute has the speed of the wind in a horizontal direction over the ground. In a wind of 30 miles per hour one might just as well jump off the roof of a closed motor car going at that speed. On October 3rd last year, Miss Boyden established what is easily a record for contempt of danger by jumping from a machine when the wind was 90 miles an hour in the air and 60 miles an hour on the ground. She jumped at 300 metres, drifted 2,800 metres, using a 28ft. parachute. She luckily landed in a marsh almost unhurt, but narrowly escaped drowning. She might just as well have jumped out of the Holyhead express going at full speed.

Swinging, which often occurs during the descent, may cause the aviator to land heavily on his back or even head.

Within narrow limits, a parachute may be guided if the passenger is within reach of the rigging lines, but owing to the length of life-line necessary to connect the aviator to his parachute, in some types of aeroplane parachutes the means of dirigibility are usually beyond his reach.

For military use devices for reducing the effective area by peripheral contraction of the mouth or otherwise so that the speed can be greatly increased in order to avoid the attentions of an aerial enemy who persists in amusing himself by firing at the parachutist, may be useful.

It is quite a general opinion to suppose that parachutes frequently fail to open. That opinion is wholly fallacious. During the war the ordinary parachute stuffed, more or less anyhow, into the Spencer C. case only failed to open once in every two hundred times. Failure to open is due to the fact that the rapid descent of the parachute converts the vent-hole at the apex into an air ejector; a vacuum is thus formed inside the parachute.

The vacuum causes the sides to stick together and so tends to keep the mouth closed. In 199 cases out of 200 air enters at the folds of the mouth and, overcoming the vacuum, inflates and develops the parachute. In the Autochute this tendency is ingeniously and simply overcome by inserting a sheet of paper inside the vent hole of the parachute, thus preventing the formation of a vacuum there. If it has not already done so before, the paper bursts as soon as the parachute is fully open and has taken up its load.

In the French Ors parachute, the American Folmer Clogg and the English Blackburn, Salvus and Guardian Angel, the mouth of the parachute is automatically and positively opened as the parachute leaves its container. This makes failure to open impossible. Positive opening is a vital necessity on all parachutes. Without it there is no certainty how soon the parachute will open or whether it will open at all. Anyone will agree that unless you can rely upon a parachute opening before it has fallen, say, 150 feet, the parachute is practically useless for aeroplane work, where so many of the accidents and derangements occur near the ground. It is equally important that the parachute should not open too soon or it may get foul of the falling machine. The ideal parachute must do the same thing in the same way in the same time, time after time. It ought to be possible to arrange or predict with precision the exact distance the aviator will fall before the parachute opens. With equal speeds and weights the depth of free fall must be a constant.

Next in importance to positive opening is positive extension, that is, the extension lengthwise ought to be effected by some positive reaction and not merely by air friction or inflation of the parachute.

The more positive and the better controlled these operations are, the more reliably will the parachute function.

During the war, quite five per cent. of parachutes emerged from their cases

with tangled rigging lines. In several cases the tangles were so close up to the parachute that the mouth only partially opened, the terminal velocity was excessive, and the aviators were severely injured. Tangling can be obviated only by making the rigging lines tangle-proof; this has been done by one maker. It is an indispensable safeguard and should be universally adopted. It is not difficult to do.

To be entirely practical, a parachute must be installed in an aeroplane so that it can be automatically delivered to either side of the machine when the machine is in any position. The system of installation necessarily differs with the different types of machines.

In single and two-seaters, the parachutes, if not of the knapsack type, are usually installed in compartments in the fuselage from underneath which they issue automatically on the fall of the aviator, or in the top fairing, whence they are ejected by means of catapults operated automatically.

By far the greatest danger of parachuting is landing. One may land on a house, on live wires, or in front of a train. If there is a strong wind blowing, the aviator is dragged along the ground, and seriously injured or killed, by the parachute acting as a sail.

The power of a parachute impelled by the wind is incredible. Six strong men are helpless to hold it in only a 30-mile an hour wind.

A sharp knife is often supplied for the purpose of severing the life-line on landing, but it is just as often forgotten at the moment of jumping or lost on landing. The only real safeguard is some form of quick release, of which there are very many patterns. The quick release must be proof against tampering on the way down, and against premature operation, or it will kill more than it will save.

The most dangerous predicament is to land on the roof of a building in a wind. Nothing but an instantaneous release and prompt action will prevent the parachutist from being dragged off by his parachute and killed. Viola, a professional lady parachutist, was killed in this way at Coventry in 1911. She landed on the roof of the Centaur Cycle Works.

Demonstration drops from aeroplanes are usually made by experienced parachutists under the most favourable conditions from machines flying on an even keel over safe ground. The demonstrators do not, as a rule, trust themselves to quick releases, but if a wind is blowing they take care to extricate themselves from their harness shortly before reaching the ground.

The unreality of demonstration drops has often been criticised as forming no criterion as to what would happen and how people would act in an aerial emergency. Opinions naturally differ widely on this conjectural point. It is said that the passengers would not, and often could not, quit the machine. It is, however, merely a question of incentive and of personal selection.

In cases of fire in the air, happily rare, but not yet entirely extinct, people would jump without thinking twice. There is always the reflection that if you jump you may be killed, but if you remain in the machine you are certain to be.

Panic will seize air passengers, just as it seizes people in earthquakes, shipwrecks, etc., but those that keep their heads will make use of their parachutes if in their discretion it is imperative to do so.

The saving of passengers by parachute from multi-passenger machines is the biggest problem that the parachute expert has to solve. A solution has just been patented in which one huge parachute has been designed to lift from the aeroplane the cabin complete with its human contents, even at a few feet from the ground. The decision and operation are placed in the hands of the pilot.

The invention needs trying out and development. Its principal advantage is that the passengers are not called upon to think for themselves.

To assert, as is often done, that aerial accidents can be totally eliminated, is most pernicious, however bona fide that opinion may be in the minds of the people who state it. Aerial accidents can be eliminated no more than railway accidents, shipwrecks, and thunderstorms, in all of which every possible safeguard is provided. Life-saving equipment is only one of the safeguards. In no kind of transit is reliance placed wholly on life-saving gear to the exclusion of all other precautions, nor is life-saving gear expected to save more than a percentage of the passengers. The most ardent enthusiast does not claim that parachutes will save more than fifty per cent. of passengers, because you cannot expect stout gentlemen and old ladies to act with the experienced agility of German pilots, whose escapes at present provide the only available statistics of life-saving from aeroplanes, nor will parachutes save passengers in taking-off and landing crashes.

DISCUSSION.

Sir SEFTON BRANCKER said he had felt like a prisoner at the bar when he heard the criticisms the lecturer made as to the value parachutes might have had during the war. He had said that they could have saved 5,000 people, or something like that. He could not remember exactly why the use of the parachute had not developed more quickly. They were used in 1917 for dropping spies with very good success. He thought the delay in the development of the parachute was chiefly that the people in the field did not ask for them as they did not think they would be necessary nor successful. But when Major Orde Lees came to him in 1918 he was an absolute godsend and through his energy and enthusiasm they pushed the parachute on and got it ready in August of that year. He was very strongly in favour of the use of parachutes for war purposes. Their use covered three classes of accident—(1) fire, brought about by incendiary or explosive bullets; (2) breakage of the machine in the air, brought about by shell or machine gun fire; and (3) collision, which would be more frequent in the future in the aerial battle or "dog fight." But when they came to commercial aviation he implored the lecturer to go easy. They must take care not to rush into panicky legislation, insisting on the use of parachutes in all commercial aircraft. The task of making commercial aviation pay was already a difficult one. The lecturer talked about dividends, but no one had any dividends yet, and it would be some time before they had any. The provision of parachutes meant additional expense, additional weight and valuable space being taken up; and also in the present state of affairs, when passenger-carrying machines were usually limited by economical conditions to a small eight-passenger machine it would be difficult for the passengers to save themselves on parachutes. To deal with the three classes of accidents he had mentioned—(1) fire, well they must not allow fire in the air, there was no reason why there should be any; (2) breakage in the air was equally inexcusable; and (3) collision might come eventually, but it would take rather a clever man to collide with British machines at present! It was a curious thing that parachutes were never discovered in Zeppelins during the war. Perhaps the Germans were afraid the men would jump out in England and be prisoners rather than go back to Germany. He was glad to hear the lecturer say a soaring type of parachute had a chance of being a practical proposition. When he (Sir S. Brancker) first saw it on paper he was very keen on it. The scientists said, however, it would not only break the tail but would break the pilot's neck in pulling him out. The latest event in the development of parachutes during the last few months was when one of the starters in the Gordon-Bennett race—an American he believed—came over to France to fly a light fast machine from which he intended to drop

the undercarriage to get speed, and, having passed the winning post, was going to jump out and let the machine go as he would not dare land it. He concluded by saying that the lecturer was perhaps the bravest and one of the most enthusiastic men he had ever met.

(*Note sent to Secretary afterwards.*) I omitted to point out that in no accident which had occurred to a British commercial aircraft running on a regular air service during the last two years would the provision of parachutes have been the least use. When increase of traffic and frequent night and cloud flying make collisions possible, then parachutes must be provided.

Major G. I. Taylor said he supposed he had been asked to speak because some time ago he designed the shape of a parachute, which he now exhibited, and which did away with all those crinkles which were rather a disadvantage. It would be seen from the model that two pieces of stuff were stuck together and on blowing it up it got to a certain shape and looked absolutely stiff. It looked like two parachutes put together.

The number of occasions on which a scientific man, or a man who had done a good deal of observation, had done parachute descents from an aeroplane was comparatively small. He made one about three weeks ago. When he heard Major Orde Lees was coming to Cambridge to give a demonstration, he (Major Taylor) thought it was a good opportunity to try a new experience, so he asked Major Orde Lees to bring a spare parachute with him. The first thing he (Major Taylor) noticed after successfully clearing the control wires by means of a vigorous jump outwards was that the small strain exerted on the rope to which he was attached by the pull of the parachute in coming out of its case was sufficient to turn him upside down into a position which was comfortable for observing the parachute open. The strain of opening was quite small owing, presumably, to the design of the harness, though of course he had his forward speed of 60 miles an hour or so as well as the vertical speed due to a drop of 60 or 70 feet.

When the parachute opened the sensation of floating gently downwards was extremely pleasant, but on approaching the earth he found himself going backwards over the ground. In order not to be dragged backwards along the ground on landing it was necessary to turn so as to face down-wind. It is impossible to get any grip on a vertical string from which one is hanging so as to produce any tendency to spin one round. The problem is exactly the same as that of turning on a music stool when one cannot reach the ground with one's legs. It is also the same as that of a cat which can turn so as to fall on its feet when dropped upside down a few feet from the ground. In this case he (Major Taylor) solved the difficulty by putting his legs out, swinging them round into the wind so that the reaction swung his body round till it faced down-wind. He then brought his legs straight back under his body and found himself in the correct position for landing.

The landing itself was carried out with about the same impact as that one gets when jumping off a motor bus going at a moderate speed. After touching the ground he immediately ran forward so as to release the pressure of the wind in the parachute as it blew forward into a horizontal position. The parachute then collapsed in a perfect circle on the ground.

Parachuting can be recommended to those who like new sensations as a sport on which it is well worth while to spend a fine summer afternoon.

Major Orde Lees then gave a demonstration of the opening and dropping of a full-sized parachute which had been suspended from the ceiling of the hall.

The Chairman expressed the thanks of the Society to the author, who, he said, would reply to the discussion in writing.

CONTRIBUTED.

Major Orde Lees is to be congratulated upon the production of a paper of considerable interest to those who have concerned themselves with the question of providing means whereby aircraft personnel may be given an avenue of safety in the event of disaster whilst in the air.

The parachute has been, not inaptly, termed the "lifebuoy of the air," and whilst under a disadvantage with respect to its marine counterpart in the small space of time within which it must be brought into operation, it has the advantage of bringing its passenger safely to terra firma, whereas an ordinary lifebuoy is only useful in conjunction with boats or other auxiliary assistance.

The figures quoted by the author as to the number of German pilots saved from damaged machines during the latter phase of the war are very remarkable, and if, as he suggested, they could be officially authenticated the value of aeroplane parachutes would be placed in an unassailable position.

I should like to correct what appeared to be a serious error made by the author in his attempted classification of types of parachutes. From his remarks it would be inferred that with the "Salvus" parachute it was necessary for the passenger to perform certain operations *after* jumping from the aeroplane, whereas this parachute is entirely automatic and, as a long series of trials have demonstrated, embodies four fundamental requirements of a satisfactory aerial life-saving device, viz. :—

(1) *Automatic Action.*—So that the passenger has to perform no other act than to leap or fall from the machine.

(2) *Instant Detachment.*—So as to avoid fouling the tail skid or other part of the machine in the case of a spinning dive.

(3) *Positive Opening.*—To ensure the functioning of the apparatus within a short and known length of fall.

(4) *Small Shock of Opening.*—To provide for comfort of the passenger and avoid undue stresses in the apparatus without the use of springs, dashpots, or other shock-absorbing devices.

With respect to the risk of parachutes fouling the aeroplane when used from a machine in a spinning nose dive, there is, of course, no likelihood of the parachute being wound up like string round a peg-top as some people imagine. But the author appears to dismiss the real risk far more airily than is justified if careful consideration is given to the time-sequence involved in such a manœuvre.

A parachute when extended to full length measures about fifty feet from apex of silk body to passenger, and types that require to be fully extended before finally leaving the container require about one and a quarter seconds from the time the passenger leaves the machine before they become fully detached when used from an aeroplane flying level.

If the machine is diving, the relative acceleration between machine and passenger is reduced to less than $g = 32$ with a corresponding increase in the time required for detachment, which may reach three to four seconds.

Apparatus of this slow-detachment type is quite suitable for leaving a machine that is flying level under control providing adequate precautions are taken to prevent the silk body being damaged by the tail skid.

But many machines when spinning have a period of spin from three to four seconds, so that in one second or less the rearplane will be standing at 90 degrees to its position when the passenger left the machine and practically form a tail skid some eight feet long threatening the delicate fabric of the silk body.

One method of attempting to overcome the above difficulty, as mentioned by the author, is to drop the entire parachute in its case on the end of a rope.

An objection to this is that the mass of the parachute (probably about 20lbs.) moving with the velocity due to a fall of many feet and accentuated by the action of the slip stream, has to be suddenly checked with a considerable resultant shock which synchronising with the effort of opening the container may entail very heavy stresses on the connections to the aeroplane with possibilities of breakage, or necessitating the addition of special shock-absorbing apparatus.

The author mentions the possible evolution of a parachute designed to rise above the fuselage and lift from the machine the entire cabin complete with passengers, and if this scheme can be satisfactorily worked out in a simple and practical manner it should offer considerable possibilities for civil aviation by overcoming the difficulty of getting a number of untrained persons away from the aircraft with sufficient celerity.

ERNEST E. SMITH.

LECTURER'S REPLY.

When Sir Sefton Brancker says he feels like a prisoner at the bar, I hasten to re-assure him that, though I admire his customary magnanimity in taking on his own broad shoulders the responsibility for not having adopted the aeroplane parachute earlier in the war, my indictments were entirely impersonal and so far from his being an obstructionist in the matter he was the first and the readiest to appreciate the life-saving potentialities of the aeroplane parachute.

As Sir Sefton says that these parachutes were got ready in August, 1918, it really is a scandal that not a single Air Force pilot has ever yet flown on a machine with a parachute fitted to it as standard except experimental machines after a lapse of over two and a half years.

It is all very well to say that accidents of various kinds are inexcusable, but you cannot entirely eliminate aerial accidents any more than you can railway smashes, shipwrecks, or thunderstorms, where every precaution is taken to save life.

The question of cost is a hard one to face, but conceive the public outcry if lifeboats were removed from ships because they cost too much. No price is too great to pay when human lives can be saved. It is an argument that was used by the R.A.F. in April, 1919, and one which I will violently oppose as long as my pen holds ink. I do not see why legislation on the point need be panicky.

The question of weight and bulk and consequent reduction of carrying and earning capacity is merely a question of urgency. Lavatories are so much waste space and passengers are often too bashful to use them; still they are considered necessities.

It is difficult for passengers to save themselves with individual parachutes, but desperate men make desperate efforts, and Sir Sefton does not use the word impossible, indeed, he goes so far as to say that he is in favour of the use of parachutes *for war purposes*. I do not think he makes at all a good case for the distinction between war purposes and travel purposes.

I think the reason given by Sir Sefton for the absence of parachutes in "Zepps" is the right one. I have been told that they were removed at Ostend. When the Germans began to use parachutes in aeroplanes an unscientific observer reported that their parachute was lifting the pilot out of the falling machine. Am I not right in saying that Sir Sefton was influenced by this report, which I was certain at the time, and have since proved, was an unintentional misrepresentation.

I should like to shake hands with the Gordon-Bennett Yank who proposed dropping his undercarriage and later himself by parachute. I should like to

subscribe to the final obsequies of the people who helped to stop the under-carriage and the aeroplane after our friend had no further need of them!

I have always regarded Major Taylor with reverent awe as the arch-figure-juggler of aviation. How a man can design a floppy thing like a parachute mathematically, and get it right, too, is quite beyond my limited comprehension. But when such a man comes and does an ordinary parachute descent he seems to come off his pedestal down to the earthly plane once more on a level with myself.

Major Taylor's contribution is a very wonderful parachute which, for its weight and area, has a much lower terminal velocity than any other parachute. In it he has eliminated the inefficiency due to "fluting" at the periphery.

T. ORDE LEES.

The CHAIRMAN said before calling upon Mr. J. W. W. Dyer to read his Paper on "Airship Fabrics" he would like to tell those present a few things about him. Before joining the Airship Service in 1915, Mr. Dyer was the author of several works on the chemistry of cellulose. He joined the Airship Service in 1915 at Kingsnorth and became assistant chemist at that establishment, where he worked mainly on the determination of the permeability of airship fabrics, and the circumstances which governed the loss of gas-tightness and loss of strength in those fabrics. Since the end of 1918 he had been chief chemist, and had been engaged on important airship research work. During the last nine months he had been directing experiments of exceptional importance in exposing various gas-bag and outer cover fabrics to the tropical conditions of Egypt. A large proportion of those gasbags and outer cover fabrics had just come back from Egypt, and Mr. Dyer was now studying them closely and reporting officially on them. So he thought it would be seen that Mr. Dyer could speak with great authority on his subject.

Mr. J. W. W. DYER then delivered the following lecture :—

AIRSHIP FABRICS.

A proper treatment of the construction and properties of airship fabrics would require a book rather than an essay. In what follows, it is possible therefore to deal briefly only with the principal types of fabrics, classified according to the main functions of each, describing their structure and behaviour and the chief factors affecting their permanence when in service.

There are, then three main classes :—

I. Fabrics for the envelopes of non-rigid airships.
II. Fabrics for the gasbags of rigid airships.
III. Fabrics for the outer covers of rigid airships.

In all cases low specific weight (expressed here in grammes per square metre*) is clearly of the greatest importance.

I. Fabrics of this class must possess gas-holding properties, mechanical strength and pliability. The internal pressure (equal to about 30mms. of water) which maintains the shape of the envelope sets up in its fabric considerable tension, and this is increased by the distributed weight of the whole ship.

Non-rigid envelope fabrics are normally of rubber-proofed cotton. The number and weights of the plies of cotton and the total weight and distribution of the rubber depend on the precise purpose for which the fabric is intended.

Some typical fabrics may be illustrated by reference to standard British practice. Cotton cloths are used having the weights and tensile strengths given in the following table :—

† gms/$m^2 \div 34 =$ ozs./yd^2 correct to about 1%.

Reference letter.	Weight gms./m².	Strength kgs./m.
B	110	1100
C	80	800
D	65	650
E	45	510

It will be observed that all have nearly the same specific strength or a common breaking length† of about 10,000 metres. Cotton is used in preference to linen largely because its greater uniformity and smoothness make it more suitable material for the proofer. Single-ply fabrics are not used for several reasons. In the first place, local defects might cause serious weakness; secondly, they have little resistance to tearing when wounded; thirdly, a sufficient weight of rubber proofing of proper quality placed between two cotton plies gives greater gas-tightness than the same weight and quality used as facing of a single ply. In two and three-ply fabrics the plies are held together by the rubber proofing which is also the gas retaining member of the compound fabric. On the outer cotton face is placed either camouflage colouring or a layer protective against the weather or an attempt to combine the two. Typically the protecting layer is of a special rubber proofing having a surface of aluminium powder printed on it. The following schemes represent normal two and three-ply fabrics such as are used respectively for small non-rigids and for the top lobes of large trilobe non-rigids. The letters represent cottons of the above standard types.

Two-Ply.	Three-Ply.
B	C
Main gas holding rubber, 100 gms./m².	Main gas holding rubber, 100 gms./m².
(C)	(C)
Outer protective rubber-aluminium layer, 50 gms./m².	Rubber layer, 30 gms./m².
	C
	Outer protective rubber-aluminium layer, 50 gms./m².
Total Weight, 340 gms./m².	Total Weight, 420 gms./m².

The letters in brackets ( ) indicate a ply laid with its yarns at 45 degrees to those of the other ply or plies, *i.e.*, diagonally or on the bias. This greatly increases resistance to tearing and is discussed more fully below. It may be stated here that rubber is chosen as proofing material not because, for a given weight, it has the lowest permeability to gases of all readily accessible plastic materials, but because other media which may be excellent for low permeability have disadvantages of one sort or another from which rubber is free. Goldbeaters skin, oil proofing, gelatine proofing are all excellent for gas-tightness, but expense, fragility, slow production of the first, defective strength and difficulty of seaming of the second, and in the case of gelatine dependence for useful life on retention of moisture not possible in hot dry climates, are reasons (among others) why these substances as at present applied are inferior to rubber for the purpose of non-rigid envelope construction.

It will be convenient to treat the tensile, gas-holding and weathering properties of rubber-proofed fabrics in separate sections.

(*a*) *Tensile properties.*—The standard cotton fabrics of the table already given will be regarded as the basic materials having the strengths there stated, and this section will discuss the strengths of balloon fabrics, built up from them, when tested in various ways.

The simple tensile strength is normally measured on a piece of 5 cms. width and about 20 cms. (effective) length. The ends of this test piece being secured in suitable clamps, it is then treated so as either

† *i.e.*, a length which would break under its own weight, often a useful basis of comparison.

(*a*) To stretch it at a constant rate, or
(*b*) To increase the load on it at a constant rate till it breaks.

The second, the constant rate of loading test, is the one usually employed in experimental work and now insisted on in contractual testing, and all tensile tests discussed here have been made in that way. A figure purporting to give the strength of a cotton fabric is highly arbitrary. This will appear more fully from what follows, but it may be stated here that it depends on the kind of machine used ((a) or (b) above), the humidity conditions of the fabric, and this, if equilibrium has been reached, depends on the temperature[1] and humidity of the ambient air. Further, the apparent strength depends on the rate of applying the load during the test. The higher the humidity and the faster the rate of loading, the greater is the apparent strength.[2]

When in use, the fabric is under compound stress and it is clearly desirable to be able to predict its behaviour in such conditions from the simplest tests on small pieces. The range of data available is not such as to make this possible for all two or three-ply fabric combinations that might be selected, but a good deal is known with reference to certain much-used types. The points of interest are obviously :—

(i.) The strength of the two and three-ply fabrics in simple tension and the relation of this to the strengths of the component cloths.
(ii.) The strength of wounded fabrics.
(iii.) The relation between simple tensile strength and the result of various compound stress tests including bursting.
(iv.) The effect of a sustained load.

(i.) In tabular form below are given the strengths in simple tension of a number of two-ply fabrics. Their structures are indicated by letters signifying standard cottons from Table I. Letters in brackets signify bias ply. All results are in kilos/metre.

T = strength of compound fabric.

t_1 and t_2 = strengths of component plies, t_2 being used for the bias ply. The t_2 of columns 6 and 7 is the mean of the warp and weft values.

Figures in brackets denote strengths as specified in Table I. and not actually found by testing the separated plies.

1. Structure of fabric.	2. Direction tested.	3. Kilos. T.	4. per t_1	5. Metre. t_2	6. $\frac{T}{t_1\ t_2}$	7. $\frac{t_2}{t_1\ t_1}$
A (D)	Warp	1560	(1250)	(650)	.82	.66
B (C)	Warp	1306	(1100)	(800)	.69	.56
B (C)	Warp	1183	980	626	.75	.62
	Weft	1234	1080	580	.73	.64
C (C)	Warp	1025	800	844	.64	.50
	Weft	932	653	753	.64	.45
D (D)	Warp	742	635	553	.60	.56
	Weft	707	562	463	.58	.53
BX (BX) ...	Warp	1000	625	852	.69	.43
	Weft	1000	635	800	.69	.43
CC Parallel ...	Warp	1705	(800)	(800)	1.06	.5
	Weft	1580	(800)	(800)	.99	.5

[1] The distribution of moisture between the air and the cotton depends on the temperature.

[2] It would appear that the different results given by different types of testing machine should be explicable on this ground. The writer has, however, data which conflict with this view, but they cannot be discussed here. It is doubtful whether comparisons under carefully controlled or observed conditions have been made.

It will be observed that there is a variable difference between the numbers in columns 6 and 7, this difference being related to the support in simple tension given to the straight ply by the biassed. A direct tension test on a diagonally doubled fabric is of course somewhat unreal and unrelated to the conditions obtaining in actual service. It is a rough guide only, and the above figures are to be regarded as fairly typical while not serving for the deduction of any rule applicable to all bias doubled fabrics.

(ii.). Resistance to tearing, *i.e.*, to the indefinite extension of a small wound, is very important for non-rigid envelope fabric. It is a property conferred on the fabric by the presence of the bias ply, whose marked influence in this respect is shown by the figures given in Table III. Tearing or wound strength is given for an initially wounded test piece by the expression

$$\frac{\text{Load to produce tearing}}{\text{Width of test piece.}}$$

Provided the test piece is large enough to include the area of non-uniform stress distribution[1] caused by the presence of the wound in the stressed specimen, the value of this expression is independent of the width of the test piece and for a given form and size of wound is a characteristic of the fabric. In Table III. it is expressed as a percentage of the strength of the unwounded material. The results relate to test pieces 6in. wide by 20in. effective length having transverse central cuts. The column headed b/s gives the ratio

$$\frac{\text{Strength of bias ply (or plies)}}{\text{Strength of straight ply,}}$$

and the percentage wound strength is seen to increase with increase in this ratio.

Further reference to factors affecting tearing strength is made in a later section on weathering.

Fabric.	Tearing strength as percentage of full strength. ½″ cut.	1″ cut.	1½″ cut.	b/s
1-ply proofed C	40	22	19	—
CC parallel	33	24	18	—
Plain 1-ply linen (130 gms./m^2	52	41	33	—
B (D)	57	46	41	·59
B (C)	62	45	—	·73
C (C)	72	59	51	1.0
D (B)	79	69	63	1.7
C (C) C	50	35	—	·5
CC (C)	88	—	—	2.0

(iii.) The behaviour of fabrics both unwounded and wounded under compound stress conditions has been studied in three principal ways :—

(*a*) By loading the arms of a cross-shaped piece the central square is placed under compound stress, the ratio of the two stresses being variable at will. There are, however, few results by this method, particularly on biassed fabrics. It has the disadvantage that the stress on the test square is different by an unknown amount from that calculated as the quotient of the load by the width, on account of enhanced stresses which exist at the corners of the square.

[1] The so-called " danger rectangle."

(b) Small cylinders of fabric 5in. diameter and 30in. long having metal end pieces have been used. They were subjected either to pressure above or to pressure plus further longitudinal tension by loading them as they were held in position between the grips of a fabric testing machine. In other cases, using similar cylinders bursting pressure only was applied with no additional longitudinal tension. From tests of this nature with small cylinders the values for the ratio

$$\frac{\text{Tensile strength by bursting}}{\text{Simple tensile strength}} \text{ or } \frac{T_b}{T_t}$$

were found to be 1.4 to 1.6 for various biassed fabrics, 0.6 to 1.6 for parallel doubled and about 0.7 for single ply.

(But see succeeding section.)

(c) Bursting tests on larger models.

Larger cylinders ranging up to about 3½ metres diameter and having hemispherical ends have been used by Avorio in a number of bursting experiments. He found a scale effect with cylinders up to one metre diameter such that the bursting stress decreased with increasing diameter. Beyond this up to the largest tested there was no further decrease. From the minimum results, his values for the ratio T_b/T_t were found to be 0.63 and 1.00 for parallel and diagonal two-ply fabrics respectively.

In some tests carried out a year or two ago in this country, models 20 feet long of the SS. type of non-rigid airship were used. The envelope except for one gore was of strong three-ply fabric. Gores of the experimental two-ply fabrics filled the gap, in turn being inserted by stuck seams. Pressure was supplied by means of a blower, the circumference at burst and bursting pressure was measured. Such tests were made on whole and variously wounded fabrics of three types, the wounds being made at the maximum diameter before the pressure was applied. The weft yarns took the hoop tension and there were no transverse seams. For comparison with the results of these experiments the weft strength of the fabrics in simple tension, both unwounded and wounded, were also found.

Table IV. gives the results (T_b for bursting tests, T_t for tensile tests) in kilos/metre.

Table V. gives the ratio T_b/T_t for several of the conditions tried.

TABLE IV.

Fabric.	T_b Kilos/metre.				T_t Kilos/metre.			
	No. wound.	½″ hole.	¾″ hole.	¾″ slit.	No. wound.	½″ hole.	¾″ hole.	¾″ slit.
C (C)	1110	1115	1007	825	996	707	650	620
B (D)... ...	1366	1004	920	—	1140	715	664	620
CC Parallel ...	1130	513	435	340	1250	604	500	423

TABLE V.

Fabric.	Ratio T_b/T_t.			
	No. wound.	½″ hole.	¾″ hole.	¾″ slit.
B (D)	1.20	1.40	1.38	—
CC Parallel ...	.90	.85	.87	.80
C (C)	1.11	1.58	1.55	1.33

The cottons in the three fabrics were not exactly of the weights specified in Table I. Actually the total weight of cotton was, within a very few grams per square metre, the same in each fabric. The strength figures as they stand are therefore proportional to specific strength. The results show the superiority of diagonal over parallel fabric and also how misleading, for this comparison, a simple tensile test is. The C (C) fabric has for small wounds a slight superiority over the B (D), but there is an indication that with larger ones this might disappear. The results of Table V. stand between Avorio's and those quoted in section (*b*) above. Comparative bursting and tensile tests do not seem to have been made under strictly comparable or observed conditions. Scale effect, seams, humidity, temperature and rate of loading all affect the comparison. Rate of loading affects the apparent strength of two-ply fabrics very considerably. Corresponding to rates of 30lbs./in/min. and 150lbs./in/min. differences in apparent strength of the order of 10 per cent. and 20 per cent. for two-ply diagonal and parallel respectively may be found, the higher rate giving the greater apparent strength. This is for unwounded test pieces. The rate of rise of pressure was not taken in the bursting tests described above but they probably correspond to a rate of loading slower if anything than the slower of the two just quoted. The tensile tests compared with them were made at the slow rate. Had they been at the higher rate the tensile figures would have been higher and the ratio Tb/Tt correspondingly reduced.

Strength Under Sustained Load.

IV. This is of the greatest importance, but only comparatively lately has it received attention. Work on the subject is at present in progress. The data now available from earlier work are not numerous nor readily summarised in a general statement. The figures in Tables VI. and VII. will give an idea of the behaviour of fabrics under conditions of sustained load.

TABLE VI.

Tests on warp direction of B cotton. Normal breaking load at 72 per cent. humidity and 150lbs./in/min. loading = 129lbs./2″.

Load applied.	% of Normal Breaking Load.	Time to break.
116	90	1 or 2 seconds.
110	85	A few seconds.
103	80	8 to 13 minutes.
95	75	1 to 2 hours.

TABLE VII.

Fabric.	Kilos/metre. Normal strength.	Kilos/metre. Sustained load.	% of normal breaking load.	Time to break (days).
C (C) C warp	1900	950	50	5
B D Parallel warp	1460	900	62	5
B (D) warp	1310	680	52	7
Single-ply linen 120 gms./m^2	1100	620	56	5

The fabric is not seriously weakened as a whole by sustained loading. If after the break the remaining portions be tested in the ordinary way they are found to have a strength little lower than that of new material. This behaviour of

fabrics under sustained load is clearly of great importance and introduces a new corrective to the estimates made of the stength of the fabric as compared to the stresses it is subject to in service.

The Fabric as a Gas Holder.

The two and three-ply fabrics, whose structure is described in an earlier paragraph, each contain a layer of rubber proofing of 100gms./m². It is on this principally that their gas-retaining properties depend, and in present-day fabrics a proofing layer of 100 to 120 gms. specific weight is adopted, the lower figure being the normal standard. In the three-ply fabric the second layer between plies of 30gms./m² is merely to hold the middle and outer plies of cotton together, though it will undoubtedly help to reduce the permeability of the fabric. The outer layer of 50gms./m² also helps when the fabric is new, but in use it probably ceases to function as a gas holder after a very short time while still remaining a more or less efficient protective layer. Other weights and distributions of rubber have been used, *e.g.*, in earlier three-ply fabrics two 85gm. inter-ply layers were used. In many fabrics an inner facing† has been used of 15, 30, 40 or more gms./m².

The composition of the rubber proofing varies somewhat with different makers. Normally it is about 95 per cent. hard fine Para rubber, from 1 per cent. to 3 per cent. of sulphur, often together with say 3 per cent. or 4 per cent. of inorganic substances such as lime, magnesia or litharge as accelerators of vulcanisation. Some proofers use no mineral accelerator. For standard British fabrics hot vulcanisation is specified. Experience in this country with cold vulcanisation has not been successful. There has been no attempt to set up a standard degree of vulcanisation for the two excellent reasons that no one knows which is the best one, and if they did, they would not in general be able to test a finished proofing and say whether it had or had not been brought to that optimum degree. It may be said here that the percentage of combined sulphur, a figure correlated with degree of vulcanisation for the same type of mixing, varies in British proofings from about 0.3 to nearly 2.0, though more usually between 0.5 and 1.5. No connection between this and permeability can be traced.

In testing proofed fabric, the permeability to hydrogen is measured with the fabric at normal humidity and 20°C. The figures for two and three-ply fabrics as described earlier may not exceed 12 and 10 litres/m²/day respectively. Two-ply fabrics, at any rate, are usually a litre or so below the specified figure. The connection between weight of proofing and permeability is not very clear. With rubber films there is a regular decrease in permeability as the specific weight increases. Such rubber film has, however, weight for weight, a very much higher permeability than rubber proofing of the kind just described placed between plies of cotton. The evidence on weight and permeability with regard to proofed fabrics, as distinct from films of rubber, is by no means unequivocal. In one instance the figures for a number of two and three-ply fabrics by the same maker were compared. The former had almost exactly half the weight of proofing of the latter, yet the mean permeability of the two-ply was very close to that of the three-ply. On the other hand, there are numerous examples of pairs of fabrics, each having the same between plies layer, and one having, in addition, a facing of rubber where the faced fabric has a decidedly lower permeability. Two-ply fabrics of the type already described with an outer protective layer frequently show on weathering a small immediate rise in permeability, and then if the protective coat is a good one, no further rise for a long time. This change corresponds to the early breakdown of the protective layer as a gas retainer which function is clearly performed to some extent when quite new. There are data

† *i.e.*, next to the gas and therefore sometimes called the "gas layer," a term open to objection. In the schemes for two and three-ply fabrics given earlier this layer would head the list.

of these kinds in abundance, but they do not settle the point. They all deal with comparison between one and two and three layers of proofing. There is unfortunately no set of permeability data for a series of fabrics having different weights of inter-ply rubber of the same kind and applied in the same way. This matter of permeability and weight has an obvious practical bearing, and it is of some theoretical importance in connection with the mechanism of the passage of gases through rubber membranes.† In practice, for framing specifications, the rough view is taken that the more proofing there is the better the fabric should hold gas. This is demanded and obtained. The fact that this has no bearing either way or any theory since the specification requirements may leave the proofer, or at any rate the ideal proofing with, so to speak, plenty to spare, leads to a further observation.

The material used for the (statistical) investigations, by which it was sought to discover what relationship, if any, existed between weight of proofing and permeability, may have been very unsuitable. The method of spreading is very important for the attainment of low permeability. It is necessary to spread a 100gm. layer in a number of thin successive coats. The proofers who made the fabrics from which the statistics were obtained were working to specification, and had merely to keep the permeabilities of the different types below or not exceeding certain values. The fact, therefore, that with 200gms./m^2 and with 100gms./m^2 of proofing they produced fabrics with nearly identical permeability proves—well, it proves that they did it, and not very much more unless it is quite certain that in each case with the large majority of pieces proofed the very best possible spreading was being done.

It may be stated here that it is possible too much stress has been laid on low permeability to the neglect of other qualities, particularly endurance. Standards, of course, have to be set up, and they imply measurement. Permeability is readily measured, but up to now no endurance test that can be usefully incorporated in a specification has been devised. "An English Summer," which was once suggested as a trial period, is scarely a standard quantity. (The question of endurance is discussed more fully in the sequel.)

Permeability is largely affected by temperature, to some extent by humidity, and probably by tension. The first, the temperature effect, has been studied fairly well in a preliminary manner. The temperature coefficient of permeability is positive and large, viz., about 4 per cent. to 5 per cent. per 1°C. Higher humidity lowers permeability, but the effect for humidities short of saturation is small for normal fabrics. The effect of tension does not seem to have been examined. To test the permeability of fabric in tension would not be easy with any of the existing forms of apparatus unless the tension were produced by high excess gas pressure on one side and that would introduce undesirable complications. Small pressure excess has little effect on permeability. It was usual to test with a hydrogen excess pressure of 30mms. of water, but it makes no practical difference if the gas is at atmospheric pressure, at least with normal fabrics.

The permeability test to hydrogen is the one that is always made. Yet permeability to air is in many ways the more important property of the fabric. The loss of hydrogen through permeability is usually small and not costly to replace. But the entrance of air lowers the purity of all the gas in the envelope, reducing lift and tending towards the formation of an explosive mixture. The passage of nitrogen and oxygen through rubber proofing does not take place at rates in accordance with Graham's Law. Diffusion proper may be operative, but it is masked by some other effect, probably differences in the absorption of the two gases by rubber. Measurements on air, nitrogen, and oxygen permeability have been made for a number of airship fabrics. Taking the hydrogen permeability

† It is not possible to discuss this here. Anything adequate would be lengthy.

as unity values for oxygen at 15.5°C. ranging from .25 to .32 were found, and on one fabric for nitrogen the value .14.

These values may, of course, not be correct at other temperatures.[1] It follows from these figures that, from air, nitrogen enters the envelope about twice as fast as oxygen (assuming permeability proportional to partial pressure). In (qualitative) agreement with this, it is found that the non-hydrogen fraction of the gas in the envelope is richer in oxygen than ordinary air is. When the amount of impurity is small the proportion of oxygen is greatest,[2] and as the total impurity increases it approaches more and more to air in composition as regards oxygen and nitrogen. There are two (or perhaps three) reasons for this. The rate of entry of oxygen will fall off faster than that of nitrogen because the difference in partial pressure of oxygen on the two sides of the fabric will diminish more quickly than the corresponding value for nitrogen. Secondly, to make good actual loss of gas the envelope will be repeatedly replenished with fresh hydrogen which usually contains 0.5 per cent. of nitrogen and no oxygen. Possibly there will be a small amount of leakage of unchanged air inwards, *e.g.*, from a hole in a ballonet. The subject of air permeability needs further study both for fabric and for seams in fabric.

Seams themselves are frequently responsible for a considerable fraction of the total loss of gas from the envelope, the loss taking place through the stitch holes. Unstitched seams, simply overlapped and taped on both faces have, if properly made, a lower permeability over their area than over the same area of the plain fabric. Stitching adds nothing to the strength of the seam. It cannot do so since a properly made stuck seam is stronger than the fabric which it unites. Yet for a number of reasons that need not be discussed its use is persisted in and the resultant bad effects on permeability have to be overcome as much as possible. The passage of hydrogen laterally along the textile components of the proofed fabric is the principal cause of seam leakage. How this may operate is seen most easily by constructing diagrams of simple overlap, overlapped and taped, overlapped, stitched and taped seams. The first is leaky; the second is theoretically[1] gas-tight, not because the tape is gas-tight, but because the rubber solution used seals the cut edges of the textile. The third is leaky, on paper and in practice. An earlier reference was made to fabrics having an inner facing of rubber of 15 to 50 or more gms./m^2. Various functions have been attributed to this layer from time to time and they need not all be discussed here. One of them is of importance in connection with seams, really only with stitched seams. If two lengths of stitched and taped seam be made, one in two-ply fabric having no inner face of rubber and the other in rubber-faced fabric, the seams in the latter will, other things being equal, be found to be very much more gas-tight than those of the former. The inner facing prevents the lateral passage of hydrogen along the cotton into the shaft formed by the stitch hole. There is no doubt at all about this effect. It is, however, not certain that the whole inner facing is functioning. In one test, some seams were made with fabric as described and tested. From some of the pieces the rubber facing was removed[2] up to the edges of the seam, but the seam permeability of these pieces was no higher than that of the others. It is quite possible, too, that the good effect of the extra facing can be produced by thorough impregnation of the first coat or two of inter-ply rubber. This experiment is being undertaken.

Seam permeability is stated in litres/lineal metre/day. From tests on pieces

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[1] It is stated that at 40deg. C. the air permeability is equal to the hydrogen.

[2] In the " air " impurity as much as 40% (instead of 21%) has been observed to be oxygen. On the figures given for oxygen and nitrogen permeability so high a figure should not be possible, but the discrepancy is not large.

[1] And practically too in the sense explained earlier in this paragraph.

[2] This may be done by rubbing gently with a piece of raw indiarubber

having seams across them the permeability in these terms can be calculated if the fabric is sufficiently uniform for an estimate to be made of the permeability in the non-seam region. With rubber-proofed fabrics an approximation is possible, but the better the seam the greater the uncertainty as to how much is real seam permeability. The seam, of course, occupies a certain area, say 400 sq. cms. per metre of seam. From this it can be seen that with normal fabrics of 10 to 12 1s/m²/day permeability there is no real excess of permeability due to the join when the seam permeability is of the order of 0.5 1/metre/day. In non-rigid envelopes the total length of seams in fabric separating gas from air is very roughly 2 metres for every square metre of fabric. Seam leakage need therefore only be about 5 1s/m/day in order to double the all-over permeability of the envelope. This figure is frequently exceeded and may indeed rise four or five-fold with unfaced fabric even when new. Good workmanship can however do much to keep down seam leakage even with fabrics theoretically bad for seaming, and it means in this case plenty of rubber solution well rubbed in.

The above summary relates principally to new seams. There is not much systematic information about different types of used seams. Another aspect of seam leakage that needs attention is that of their air permeability under various pressure conditions and its relation to loss of purity of gas in the envelope.

Endurance and Deterioration.

Good rubber-proofed fabrics that are stored at a normal temperature and shielded from light retain their properties unaltered for a long time to be measured in years. In service they deteriorate more or less rapidly, the cotton losing strength and extensibility and the rubber becoming more porous, usually consequent upon discernible chemical change. The agents causing deterioration are light, heat, and tension. Of these the principal one, either directly or indirectly, is light. In the development of airship fabrics it is noteworthy how one point at a time has received almost exclusive attention. In the early days it was insufficient scouring, acidity in the cloth and means of overcoming it.[1] Then the importance of protection from light was to the fore, the nature of the aluminium facing was considered, and the necessity for a pigmented layer under the aluminium (still imperfectly practised) insisted on. There is still more to be done on this subject, but it is, in the writer's opinion, time that tension effects had their turn. This view is based on experiments made during last summer which will be referred to briefly later in this section.

The action of light on cellulose has been studied by Aston, who used linen thread. No doubt the results apply also to cotton. He found that visible light has scarcely any effect and that the specially active rays are in two groups in the ultra violet. He further found that the rapidity of attack was greatly reduced by the removal of oxygen. In agreement with this it has been shown that the product of the action of ultra violet light on cotton in air has the properties of the oxycelluloses. The textile cannot, of course, be protected from oxygen, but it can be more or less completely shielded from light. The rubber is oxidised in light and air, and apparently even more readily so is the free sulphur always in the proofing. The sulphuric acid arising from this is a further cause of deterioration of the cotton. It may be observed that some of the free sulphur nominally in the proofing is, in a new fabric, actually in the cotton textile, and on oxidation is favourably situated for attacking the cotton. It is noteworthy, too, that light stopping protective facings, judged to be good by the fact that the inter-ply rubber deteriorates very slowly, do not prevent the relatively rapid oxidation of the free

[1] It should have been mentioned earlier in describing the standard cottons that they are specially scoured and afterwards treated with a dilute weakly alkaline substance, sodium acetate, to counteract acidity. These processes were worked out about 1915 at the Manchester School of Technology.

sulphur in the top textile and inter-ply rubber. The rate of oxidation of the rubber may be judged by the acetone extract it yields. In a well-protected inter-ply rubber whose acetone extract on six months' exposure (January to June) only increased from 5.1 per cent. to about 7 per cent., the sulphur decreased from 1 per cent. to 0.25 per cent. Heat accelerates the decay of rubber in the light, and also the attack on the cotton of the acid from free sulphur. The action of heat alone on rubber in the absence of light is not comparable with the action of light. No judgment of the probable weathering quality of a proofing can be based on heat treatment tests. Experiments on the artificial weathering of proofed fabrics using the mercury vapour lamp have not proved a satisfactory substitute for exposure out of doors. Cotton is relatively more and rubber much less attacked by the ultra violet lamp than in the natural weathering test.

Methods of protection.—All these aim at keeping light away from the rubber, cotton or both. They include :—

(i.) Reflecting facings of aluminium.
(ii.) Pigmented rubber facings.
(iii.) Dyes in the rubber.
(iv.) Dyes in the cotton.

Fabrics could be selected to typify each of these four methods used separately as well as (i.) with (ii.) and (i.) with (iii.).

It is important to reflect as much light[1] as possible, and in British airship practice the aluminium facing has been relied on for this, no systematic use of, *e.g.*, white pigments in addition have been made.[2] No aluminium facing alone has ever been successful in giving good protection. The best facings are made by printing aluminium powder on the rubber protective layer. Aluminium facings are nearly always patently discontinuous even when new. In some cases large amounts of the powder have been incorporated in the outer rubber layer, but this weathers badly and soon falls off. A printed aluminium facing used in conjunction with a suitably pigmented rubber layer immediately beneath has been found the best of all methods yet tried in service if the protection of the fabric as a whole be taken as criterion. The only pigmentation that has been much used and found successful is customarily referred to as the "heavy litharge" layer. It is simply the use of a high percentage, up to 20 per cent., of litharge in the outer rubber layer. Its virtues have been attributed to opaque colloidal lead sulphide formed by reaction between litharge and sulphur during vulcanisation. Lead sulphide is undoubtedly present, but only some 10 per cent. of the lead appears to be in this form.

Method (iii.), the use of suitable dyes[1] in the rubber, has been found very successful in protecting it from oxidation. The dyes have a marked absorption in the ultra violet. Rubber so treated may be exposed for months, at any rate, in this climate, and show scarcely any increase in either acetone extract or in permeability. A comprehensive series of weathering tests in Egypt on fabrics protected in this way is now in progress in conjunction with the manufacturers. As hitherto used, these dyes have failed to protect the cotton. In fact, no dye protection for cotton has been successful.[2] Generally, dyed outer cottons with no outer rubber have been for ground camouflage. Such dyed cottons afford slight transient protection to the rubber.

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[1] Total incident radiant energy would perhaps be a better term.

[2] One is being tried in an exposure test at present.

[1] The method has been patented by the North British Rubber Co. An example is the use of Toluene — azo — toluene — azo — B Naphthol.

[2] An alizarin dye used in an experimental fabric weathered in Somaliland was favourably reported on, but no use appears to have been made of it in practice. (Barr A.C.A., Report R and M313.)

The part played by tension is causing deterioration on exposure is very important. Until recently most weathering tests have consisted in the exposure of pieces of fabric held in a frame but not under any tension. From comparative weathering tests on pieces of fabric with and without tension it is found that the rubber in the tensioned pieces has perished more than in the untensioned. In certain fabrics a partial explanation at least is very simple. As a result of stretching under tension the outer rubber film becomes roughened and the aluminium no longer lies as a smooth layer but is easily rubbed away. Briefly, tension has made the whole fabric more accessible to light. It seems probable, however, from some other results that tension acts in other ways too. Three different fabrics were made the subjects of comparative weathering tests of this kind. Two of them had what proved to be relatively poor outer facings which roughened and fell away to some extent as described above. The other outer facing was excellent, being a "heavy litharge" rubber layer topped with a good aluminium coat of considerable permanence. With the first two there was greater loss of strength of the top ply of cotton than in that ply of the comparison untensioned pieces. With the third fabric the loss of strength was negligible both in the loaded and unloaded pieces. These strength data may be taken as some indication of the relative light penetrations, *i.e.*, considerable in the first two, little in the case of the third. Yet all these showed marked change in the inter-ply rubber. The first two signified this change by increased acetone extract and drop in permeability. The third showed a large rise in permeability and only a small change in acetone extract.

The General Course of Deterioration.

The conclusions drawn with regard to this will not in general be the same when based on exposure tests with untensioned pieces as when based on the examination of samples from actual service. Exposure tests may sometimes point to the rubber outlasting the textile. Experience with fabrics in service on the whole points to the opposite conclusion. An exception must probably be made in the case of the dye-protected rubbers. It is obviously better, since the fabric cannot be everlasting, for it to become useless through loss of gas-tightness than through loss of strength. Oxidative decay of the rubber (the inter-ply rubber here is intended) may follow one of two courses in nature of products and consequent effect on permeability. In the earlier stages there may be either a steady and decided fall in permeability, sometimes to 2 or 3 litres/m^2/day only, or a very gradual, scarcely perceptible rise.[1] Which of these two happens depends immediately on whether a soft and tacky or a more or less dry and harsh oxidation product is formed at the start. Following the fall of permeability will be a sudden and large rise as the soft product hardens or crumbles.

It is not quite clear what determines the course that will be followed. Broadly it appears to depend on rapidity or slowness of oxidative attack. If it is rapid, the soft product and lowered permeability will be encountered. If it is slow, the other product and condition. It is quite certain that in some cases, at any rate, the same proofing can follow either course according to the nature of the exposure.

The actual seriousness of a given loss of strength of the outer[1] cotton will depend mainly on whether it is the bias or straight ply. On this question of bias or straight for outer ply there have been many alternations and different practice has obtained in different branches of the service at the same time. The many reasons, good or bad, for these changes cannot be discussed here. It is now agreed to put the bias ply outside. In this case a considerable weakening of that ply means little loss in tensile strength of the whole fabric. And further, the

[1] This may be preceded by an increase on the original value within a few days of first exposure due to rapid loss of any gas-holding properties by the outer protective coat, if present.

[1] It is clear, of course, that the attack is from without.

bias ply still contributes its anti-tearing qualities not seriously impaired when it has lost considerably in strength individually. This is on condition that the rubber layer between the plies is still substantially sound. If the rubber has decayed in such a manner as to become soft and infiltrate the yarns of the textiles, glueing them into what is, in effect, a sheet of continuous material, the fabric will have a dangerously low tearing strength though it may have a good tensile strength when unwounded. For the bias ply to do its work there must be adhesion to the straight ply, but not adhesion that has become amalgamation.

Finally, on the subject of endurance, there are several cases known of large increases of permeability with no sensible chemical change in the inter-ply rubber layers. Up to now it has received no explanation.[1] It does not seem at all certain that tension on the fabric is a necessary prerequisite condition, for one or two cases of it are known to have occurred in ordinary non-tension weathering tests. It does seem probable that it is confined to one type of proofing. The increases in permeability are from, say, 10 or 12 1s/m²/day to 40 or 50 or even more. The subject is still under investigation.

Classes II. and III., *i.e.*, Fabrics for Rigid Airships.

From the foregoing short account of the fabrics of Class I. it will be seen that though there are serious gaps, a good deal of systematic work has been done and a more or less coherent body of knowledge put together. This is not true to the same extent of the fabrics in Classes II. and III., though these are and will be ahead of the others in importance. The properties and problems of these fabrics are in general quite different from those of the fabrics in Class I. One consideration of great importance for the latter does not arise in the same way with fabrics for rigids, and that is the tensile strength. The strength of the fabric of a non-rigid envelope is a principal measure of the strength of the ship in a way that is not true of either kind of fabric in a rigid airship. The strengths required for the latter fabrics are uncertain. Possibly the greatest stresses they ever experience are those imposed when the gas bags and outer covers are being put in their places in the ship.

II. *Gas-bag fabrics.*—The two requirements are low permeability and small specific weight. The strength required is not great. Other necessities as flexibility and (as far as possible) water repelling non-hygroscopic character are to give permanence to the principal qualities.

In almost all cases gas-bags for rigid airships consist of goldbeaters skin stuck to cotton fabrics. Silk and a mixture of silk and cotton have also been used. No substitute for goldbeaters skin has yet been satisfactorily applied on a large scale, though experiments on this point have been made and are being continued with other animal membranes than the true goldbeaters skin as well as with artificial films. The real goldbeaters skin is the membranous covering of the caecum of the ox. In size it varies from about 27in. by 6in. to 40in. by 10in., and in weight from 14 to 28 gms./m² under ordinary humidity conditions. The weight of skins when on the fabric will be rather greater because of overlaps, say 25gms./m² for an average single layer. For storage and transit the skins are packed in barrels of salt crystals. Before use they are thoroughly washed, scraped free from most of the adherent lumps of fat, and then soaked in a 5 per cent. aqueous solution of glycerine which appears to be preferentially absorbed from the solution by the skin to a noticeable extent. The glycerine is to maintain flexibility. The cotton to which the skins are attached is D quality, *i.e.*, 65gms./m², and it is proofed with vulcanised rubber 20gms./m². The proofing is to form a basis on which rubber solution can be spread. This is done thinly with a pad, not a brush, and several coats are used. The skins, wet with glycerine

[1] See a discussion of the matter in T.1159 and R and M.584, both reports of the former A.C.A.

solutions, are applied to this[1] and good adhesion is obtained. There is an overlap where each skin joins its neighbour. If two layers are applied, the second layer is applied to the first with no adhesive between and so that the longitudinal directions of the units of this layer are rectangular to that direction in the other layer. The strength of goldbeaters skin in the transverse direction (*i.e.*, the hoop direction in the animal's intestine) is about twice that in the longitudinal direction. When the skins are laid and the fabric is "air dry," it is sometimes varnished, in present practice an oil varnish being used. That is a brief description of present British practice. A fabric is produced having a weight usually below 160gms./m^2 when double skinned and varnished. This refers to normal humidity. The variation in weight with humidity is not large unless excessive glycerine has been used. The permeability of skin-lined fabric is not very uniform. Double-skinned fabric of the type described is frequently below 0.5 1/m^2/day. It is quite commonly lower; it is probable that most of the permeability observed in normal pieces is not through the skins but through minute faults. In German practice the adhesive used is a special glue and, at any rate recently, both skin and cotton faces after make-up are treated with a water-repellent coating. The German method and product both differ in several important particulars from the British. Experiments with new adhesives and new methods of manipulation are now in progress here.[1] Differences in behaviour and properties between the two types of fabric will now be briefly discussed in connection with the endurance and causes of deterioration of skin-lined gas-bag fabrics.

Gas-bags are protected by the outer cover from the weather and from light, and no question therefore arises of the deterioration of the textile or rubber (if used) through the action of what is, with other fabrics, the most potent harmful agency. The life of the gas-bag is the life of the skin lining, and methods of protection have for their object the maintenance of the goldbeaters skin. This is mainly a mechanical and not a chemical question. Considering first the use of rubber adhesive, the skins are stuck by its means to cotton fabric. This is very extensible even at low stresses. The skin also is extensible if it is kept in a moist condition. To do so is the function of the glycerine, which is not a softener *per se*, but which being hygroscopic, keeps in the skin an amount of moisture greater than it would otherwise have. If a piece of new skin-lined fabric of this type be broken in a testing machine, it is found that the skin remains intact up to the point of rupture of the cotton even though extensions of, say, 10 per cent. and 17 per cent. in the warp and weft directions are obtained. If, however, such a fabric be pulled on the bias and distorted with accompanying much greater extension than in the direct pull, the skin will be cracked. Or, if the skin be dry, as after exposure in warm air or low relative humidity, a small extension accompanying direct pull may be enough to break the skin. If the warmth and drying be carried still further the contraction of the skin cannot be followed by the cotton, with the result that at a region of weaker adhesion they part company and a pucker is formed. If this is smoothed out by tension in this dry condition, once more the skin will crack. If a piece of fabric which has been brought to this puckered condition by heating in a dry oven at about 70°C. be left for a time in air at ordinary humidity, it will recover its extensibility and the puckers can be pulled out without cracking the skin over them, though the separation of skin from fabric in that region of course persists.

A similar puckering and relaxation is obtained when such fabric is exposed in a climate with large variations in temperature and therefore in relative humidity. The latter and not absolute humidity is the moisture control. It appears that

[1] Numerous important practical details and workshop methods for systematic and rapid working are omitted.

[1] It is unfortunate that this paper is being written at a time when interesting developments are in their early stages and by no means ripe for description or discussion.

after a number of alternations the skin loses its power of recovery even in a moist atmosphere, and is in some way fundamentally altered.[1]

The results suggest the trial of softeners that do not depend on moisture for their action. This trial is being made.

The behaviour of glue-stuck skin-lined fabric is very different. There is no puckering on dry heat treatment with these, and they can, even when dry, be stressed considerably more than fabrics of the other type without any resultant rupture of the skin. The glue alters the extensibility of the textile and under moderate loads, at any rate, takes control. Further, the glued textile will tend to expand in a moist atmosphere and contract in a dry one, behaving in this way like the skin or, at any rate, accommodating the one component to the other. The whole question of the use of glue as adhesive including composition of glue, mode of application, pre-treatment of textile and skins, as well as after treatment of the fabric with varnishes and water-repellents, is now engaging attention, and it would not be profitable to add more on the subject now.

It may be observed that neither glue-stuck nor rubber-stuck skin-lined fabric will stand crumpling when warm and dry without serious permanent increase in permeability.

The permeability of both types of skin-lined fabric is usually, but not always, lowered by increase of humidity. This lowering with the German glue-stuck fabric is often very large. It is to be expected that this effect would be greater when glue is the adhesive. The Germans appear not to aim at as low permeability as is expected with British fabric. This is in accordance with their lavish provision of hydrogen. It is difficult to arrive at any reliable result for the all-over permeability of either type of bag. The only experimental method is to make loss of purity curves. There are numerous sources of error to consider, and even leaving these out of account the data do not lead to a hydrogen permeability result without an assumption as to the relative air and hydrogen permeabilities. It is true that loss of purity itself is the important result, but if the calculations from this to hydrogen permeability cannot be made, neither can the reverse one from laboratory determinations. Qualitative comparative results must suffice unless a fairly comprehensive investigation be undertaken of the relative air and hydrogen permeabilities of a number of skin-lined fabrics.

The skin, as already stated, has appreciable strength and contributes to the tensile strength of the complete fabric. Skins stuck with rubber also greatly increase the resistance to tearing, but glue-stuck skins do not, probably because of the impregnation of the textile by the glue. The following are typical figures for the two kinds of skin-lined fabric.

Kind of Fabric.	Tensile strength Kilos/metre warp direction. Complete fabric.	Cotton only. Skin removed.	Tearing strength for [illegible]in. cut as percentage of unwounded. Complete fabric.	Cotton only.
Rubber stuck (British) ...	825	670	65	40
Glue stuck (German) ...	860	608	40	40

Class III.—Outer Covers.

Ideally the outer cover would consist of a series of plane surfaces covering

[1] It is possible that this is a result of other changes and not directly of the humidity alternation, e.g., of the development of acidity. There is no evidence on this point yet, but it is hoped to obtain some from tests now in progress.

the rigid framework and, with this framework, defining the shape of the ship. This leads at once to the requirement that the outer cover shall be and remain taut. Further, it must be weatherproof so as neither to admit rain to the inside nor get waterlogged itself. It should also, as an extension of its waterproofness, be water-repellent. It must, for retention of its own strength and for protection of the gas-bags, be opaque to harmfully active light; and, principally to avoid superheating of the gas, must reflect as much incident radiation as possible. Added to this, it must have the lowest possible specific weight.

Linen, mercerised cotton and plain cotton have been used as the textile components. The two latter are in use at present. Various doping schemes used in the past have been only moderately successful and it would serve no useful purpose to give an account of them here. Some single-ply cotton and linen fabrics proofed with rubber having an aluminium finish were tried experimentally and subjected to weathering and other tests before the importance of tautness in the outer cover was fully realised. The dopes at first used were similar to aeroplane dopes but of less contracting power. Now that the strength of the framework is known to be sufficient, more powerfully contracting dopes, in all essentials the same as aeroplane dopes, are used. These consist essentially of cellulose nitrate or acetate, the latter having been used almost exclusively in the past, but the former is introduced in the latest doping schemes for reasons to be mentioned later. The function of the dope is first and foremost to produce tautness.[1] It is applied in a suitable solvent to a fabric already in slight tension. When the dope is dry, considerable tautening is found to have taken place, the actual final tautness being dependent on the nature and amount of the dope and the initial tension of the fabric. Light absorbing pigments are introduced for the protection of the textile. A red one, which has been found the best, consists of an oxide of iron. The top coat contains aluminium powder to provide a reflecting surface. This is only the briefest outline description of a doping scheme as now applied. A few of the more important details, additions and alternatives to such a scheme will now be briefly discussed.

The maintenance of tautness is a much more difficult matter than the attainment of a good degree of initial tautness. In a moist atmosphere the tautness is soon reduced through the absorption of moisture by the dope. It is stated that by using very little dope an ever-taut fabric can be obtained because a balance is struck between slackening of the dope and contraction of the textile, but under such conditions probably a sufficient degree of waterproofness, protection for textile and general robustness would not be attained. Experiment has shown that pigmentation of the dope (initially done for quite another reason) is one of the best means of minimising the slackening effect of exposure in moist air,[1] and the best results are obtained with pigment in every coat of dope applied. Pigmentation of the right kind is thus excellent. It saves cellulose acetate, protects the textile and maintains tautness under unfavourable conditions. The use of cellulose nitrate dope instead of acetate has to be considered in this connection, too, for it is less affected as to tautness by changes in humidity. It is actually being employed now for some parts of outer covers, and is not used throughout only because of its greater inflammability. The question of outer cover tautness, so important on account of its bearing on speed, among other things, is a rather

[1] Some apology is needed for the introduction of these elementary facts at this date in a paper to an aeronautical society. It is done for the sake of a (limited) completeness and as introductory to the further description. The great improvements in aeroplane dopes by which airship outer covers are now benefiting are largely due to the chemical staff at the R.A.E., and much of this section is taken from their reports where these matters are discussed in detail and with the support of a wealth of experimental data.

[1] It should be mentioned that earlier observations gave rise to the precisely opposite statement, but the more recent experiments referred to above are very complete and probably their authors had the earlier observations before them, and were satisfied that they were not generally true, though no mention is made of this.

bigger problem than that of the tautness of aeroplane wing covers. The areas involved are so much greater, and the view is held that dope cannot be expected to do all that is wanted in this way,[1] and in fact, the recent practice is to give assistance by attaching the cover by inside ties to diagonal wires.

Additional weatherproofness is sometimes attained by a finishing coat of varnish (containing aluminium powder). Varnish here means a flexible nitro dope containing, *e.g.*, castor oil.

In one acetate dope, linseed oil[2] is included as a water repellent, for which purpose it appears to be fairly efficient.

For the prevention of superheating there is the reflecting aluminium finish. The efficiency of this varies considerably and depends largely on the nature of the aluminium powder used. It seems possible that the reflecting power of aluminium powder might be assisted by the use of zinc white which, out of a large number of opaque substances tested, was found to possess the necessary radiation characteristics in the highest degree, *i.e.*, low absorptive power in the region of maximum sunlight intensity and high emissive power with small rise of temperature. It is probably not so effective in protecting the textile as the iron oxide pigment, but that might reinforce the zinc white in a layer beneath it.

Other problems that arise with outer covers touch the methods of applying the dope. In present practice pre-doping is used, *i.e.*, a part of the dope is mechanically spread before the cover is made up. It is then laced in place and the remaining dope (and varnish, if any) is applied *in situ*. It seems likely that this will be abandoned as not making the most of the weight of dope it is desirable to add. A light pre-doping may, however, be desirable to give a slight stiffness to the fabric to prevent distortion when putting in place prior to the doping proper.

Some of the foregoing, it will be seen, deals with proposals for methods yet to be tried, and with regard to the new practice already in operation it is too early yet to speak of its performance. It is known from many tests in connection with aeroplane fabrics to give extraordinarily good protection to the textile. For outer covers, as for gas-bag fabrics, this paper comes at a time when distinctly new methods are being tried.

In conclusion, a word or two may be added on the general methods of chemical and physical approach to the problems presented by these materials. It is probably true to say that applications of rigorous scientific methods and of well understood principles are increasing, not merely in devising methods of tests but also in working out new processes and employing new materials. Examples of this are to be found in the studies of various solvents and solvent mixtures for dopes, in preliminary researches on cellulose acetates and allied bodies, and in Aston's work on the action of ultra violet light on cellulose, to name only a few examples. On the other hand, there is a wide field where empirical methods are the only ones available, and where the only good test is in an attempt to reproduce conditions of service which the material will have to endure. All weathering tests form the main example of this kind of work. It is often, moreover, an empiricism where it is not possible to select for variation and study a single factor, keeping all others constant. In the interpretation of results, therefore, judgment and a weighing of pros and cons may take the place of logical deduction. This perhaps is no drawback, for these qualities will certainly be required in devising any new material as a result of the tests, for such material must always be a compromise.

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[1] It has been suggested that a slight positive pressure inside the cover should be maintained.

[2] It is orthodox to object to the use of linseed or other drying oil in contact with textiles on the score of tendering. It is possible that in conjunction with good light-absorbing pigments the use of such oil might be free from objection.

DISCUSSION.

Mr. C. I. R. Campbell said the paper was a comprehensive one and was written by a gentleman who was, perhaps, the greatest authority on the subject. A point which he (Mr. Campbell) thought required further consideration was the value to be given to the bias ply in three-ply fabrics. In non-rigid design the data available was very small indeed. In the non-rigid envelope the greatest possible strength was required, particularly in a circumferential direction. A bias ply was put in mainly for protection against accidental tearing, and no more was really asked of it than that. One wanted to get the thinnest bias ply that would do the work, and it was not known at present what was the minimum one could go to in that direction. He hoped Mr. Dyer would have particulars of experiments on that matter before very long. The figures he gave for sustained loads were very interesting and he (Mr. Campbell) had not seen them before. The fact appeared to be that a fabric could only sustain a tension of half its ordinarily expected breaking load, and this had a marked bearing on what were customarily believed to be factors of safety. It appeared that many of the factors of safety which were talked about for non-rigid envelope fabrics should be halved, as the loads were of a sustained character in most cases. Discussing outer covers, which was one of the subjects upon which research, or rather perhaps practice, was most incomplete. Mr. Dyer spoke of the importance of fireproofing. That was a point on which they all felt more strongly every day, and the evidence, he thought, showed that if acetate dope were used with plenty of pigment in it, appreciable fireproofness was secured. One did not get an incombustible outer cover, but one that would not burn freely if a light were applied to it. At the present time, when they were told airships were on the point of becoming extinct, it was particularly valuable to have this information collected and put forward in this authoritative manner, and they owed Mr. Dyer a debt of gratitude for having taken the work in hand.

Dr. Guy Barr said with regard to the strength of two and three-ply fabrics, the lecturer mentioned that the important things to consider were the relations between the strength of the individual fabrics and that of the complete cover, the strength of the wounded fabrics, and the effect of sustained loads. He (Dr. Barr) would suggest a further important point—extensibility under compound stress, which was important not only from the point of view of the adjustment of local inequalities when stressed, but also from the point of view of the actual volume of the ship. He referred to Table 7, bearing on the subject of strength under sustained loads. It would be seen that the largest percentage of the normal breaking load was retained in the second case dealt with (B.D., parallel warp). It looked to him as if a considerable proportion of the loss—in the first and third cases, at any rate, compared with the second—was due to the two plies coming unstuck under the conditions of the experiment, and that this would not occur to the same extent when the fabrics were in position with considerable pressure inside. The difference between 50 and 62 was not large, but it was a considerable proportion of the difference between 50 and 100. The remaining 38 per cent. was probably to be ascribed simply to the fact that the effect of rate of loading appeared to be most serious at the lowest rates. Mr. Dyer referred to Dr. Aston's experiments on the action of light on cellulose, and he (Dr. Barr) thought there was a small mis-statement there. Dr. Aston found that the light from the mercury arc produced the greatest deterioration in two particular portions of the spectrum, but the fact that he found those two particular portions was presumably to be ascribed not to the fact that those two parts of the spectrum of daylight were the most active, but that they were the only two in the ultra-violet part of the mercury arc spectrum studied in which there was any large amount of energy. Had any methods of protection been tried in which the reflecting facing of aluminium on a two-ply fabric had been combined with a dye in the cotton? For a long time people had been satisfied with a yellow dyed cotton, which protected to some

extent the rubber underneath, and the dyed cotton itself did not deteriorate extremely fast. The use of yellow dye showed a large improvement as compared with undyed fabric. These reflecting facings had been tried with pigmented rubber and with dyes in the rubber, but he had not seen any results of a combination of the reflecting pigments of aluminium with the dye in the cotton, and he thought that combination should be tried. With regard to the change in permeability, which occurred occasionally on storage, when there was no obvious reason why there should be a change; if one examined the fabric there was no evidence of oxidation nor of anything else except change of permeability occurring. In this connection there was an interesting observation made at the Bureau of Standards that in one or two cases permeability did not increase, but decreased to something like one-half of the original permeability instead of multiplying itself by 5, which was happened in the case to which Mr. Dyer referred. He did not know the explanation of it.

Colonel Richmond said he well understood Mr. Dyer's difficulty in compressing his subject into the space allowed for publication, and it was even more difficult for those who had not received an advance copy to grasp the subject properly from the précis into which the paper had been further compressed. It was a vast subject, and even the written paper did not refer to a lot of things of which he knew Mr. Dyer had intimate knowledge and on which they would all like to have information and to be able to discuss. Amongst these the most important was, perhaps, the mechanism of permeability. This was an extremely complicated business. Take as an illustration the gold beater's skin membrane used in rigid airship gasbags. This has a very low permeability to hydrogen, something like 1/200 of its permeability to water vapour. It had scarcely any permeability to petrol. These were facts which it was very difficult to explain. Also one might refer to the fact that most colloidal substances seemed to have a limiting permeability with weight. Some interesting work on this question had been done by Mr. Ritchie, late of the Kingsnorth laboratory, but it did not go far enough, and he thought this question of the mechanism of permeability should be tackled as soon as possible. He was sure it would have saved thousands of pounds during the war in that more efficient means would have been found of restoring a large number of envelopes which had to be scrapped. With regard to rubber fabrics in general, he would not prejudice the examination Mr. Dyer was going to make of the Egyptian samples by saying much, but there was no doubt that in Egypt all the dyes tried so far in the cloth were simply bleached in six weeks of ordinary weather, unless they were protected by aluminium or some other pigment. The dyes used in rubber undoubtedly preserved the nature of the rubber, but did not preserve the cloth, and of all the samples received, those coated with a heavy litharge coating outside seemed to have stood up best. With regard to skin-lined fabrics for airship gasbags, he would like to emphasise how necessary it was to obtain perfect adhesion between the skin and the fabric. There was an idea some time ago that the Germans thought it sufficient if the skin was lightly attached to the fabric, the skin merely acting as a gas-holding medium. They knew now that such a state of affairs would rapidly throw stresses on the skin which would tear it in all directions when the relative humidity of the air was low. He had repeated that experiment with synthetic films of various kinds. Provided the film was elastic and the adhesion was good, the tensile strength of the film was not so necessary as one might imagine. Mr. Campbell had emphasised the gloom of the clouds which were supposed at present to be obscuring the sun from airships, but he (Colonel Richmond) felt sufficiently optimistic about the future of them to say that gold beater's skins as a means of lining airships would not do. There were going to be so many airships that there would not be sufficient oxen in the world to supply the skins. In spite of the financial gentlemen who said there was not enough money in the country, the money would be found in other countries for aircraft development, and he was sure we should not be long in competing

successfully when once the public woke up to the possibilities of airships. With regard to substitutes for gold beater's skin, one ingenious thing the Germans had done was to grow the skins by means of bacteria, and also they found the glue used on their fabrics during the war so good that they were now making a fabric which consisted of the cotton and glue alone, without any skins, and he thought that promised very well. The aeroplane chemists had helped them enormously in the matter of outer covers, but the chief point to airship pilots, which would not strike the aeroplane chemists as being so important was the question of super-heating, the question of getting the maximum reflection from the fabric. The ideal fabric was either completely transparent—which was impossible—or a perfect reflector. Of the three fabrics which had been examined for superheating in Egypt, viz., one with an aluminium surface, one with a zinc-white surface, and one with a red or gold-leaf surface, the best was the zinc-white, which had super-heating under normal conditions of about 16deg., the aluminium had 23deg. and the red or gold 28deg. These were merely relative figures.

Wing Commander T. R. Cave-Browne-Cave said he did not know if they all realised that Mr. Dyer had really written two papers—the one he had read and the printed one. The complete paper contained an enormous amount of information on the very extensive research work which had been done on this subject. It would be as well if Mr. Dyer would add to the paper when printed in the Journal the detailed references to other people's work to which he had referred and also give a short bibliography. With those additions he believed that the paper would be for a very long time *the* classic on the question of airship fabrics.

The paper was obviously more complete in its treatment of the non-rigid fabric than where it dealt with the fabrics of the outer covers and gasbags of rigids. That was because a great deal more work had been done on the rubber-proofed fabric of the non-rigid. The conclusion generally drawn from the paper was probably that the rubber-proofed fabric presented far greater difficulties than the outer cover and gasbag fabrics of the rigids because of the deterioration of the rubber. One was frequently tempted to say "let us abandon the rubber and build up a non-rigid envelope fabric with an outer surface like that of the rigid and a skin-lined interior." That scheme failed because one had to get the necessary strength of the envelope by a compound fabric. Unless a substance such as rubber were used it was extremely difficult to build up a compound fabric which would have a reasonably good strength when wounded. Rubber was such an elastic adhesive that it allowed the diagonal ply to reinforce the straight plies to a much greater extent than was possible with anything else.

Mr. Campbell was very pessimistic about the deduction to be drawn from the sustained load tests. The only way in which the envelope stress could be increased to a dangerous value was by internal pressure, not by the rigging tensions which were limited by the lift of the ship. Excessive internal pressure was caused by a pilot's mistake and would only last at most a few minutes. It was not fair to assume that the envelope was going to be blown up to its bursting pressure for long periods. An interesting point was the question of unsewn seams. It had been established beyond all doubt that stitching in a seam was detrimental. It contributed nothing to the strength, and was a most prejudicial feature in regard to gastightness. But it did not look nice to fly about the heavens with seams that were stuck and not sewn, and for that sentimental reason non-rigid envelope seams were sewn. It was a curious state of affairs. One difficulty in tackling the question of the deterioration of rubber-proofed fabrics was the difficulty of reproducing the deterioration in an intensified form. When studying the deterioration of cellulose one could use mercury vapour lamps with fair confidence, but there was no artificial means of producing the actual deterioration of rubber in a more rapid form. He was rather disappointed that they had not had any remarks on that point from the rubber manufacturers. The

paper was, perhaps, rather pessimistic in that it drew attention to the various difficulties that were experienced, but more particularly with regard to rubber-proofed fabrics the development that had taken place was most creditable. In 1915 they started making envelopes of single-ply—a fabric designed to burst at 120 mm. pressure. They burst, however, when actually proof-tested at 25 mm. That was the state of affairs when Adam, Ritchie and Dyer took over the question. The last non-rigid deflated was the N.S.7. She was inflated in April, 1919, deflated for a purely mechanical defect three months afterwards, inflated again with the same envelope, and deflated three weeks ago because she was no longer wanted for service. To keep an envelope inflated for three years and have it still in an effective condition was a result to be proud of. Mr. Dyer was now free to get on with the question of the rigid fabrics, and he thought they were all confident that he could meet with corresponding success.

M. J. L. Lake said that in going through an Elizabethan Grammar School last summer he found in the Hall the words "Disce aut discede"—"Learn or get out." The rubber manufacturers had done their best both a few years before the war and during the war to learn the requirements of balloon and airship work, and they had no desire to get out in spite of what had been said in the House during the last few days. They felt that there was a great future for airships.

He would like, as being perhaps the only representative of the manufacturers present at the lecture and only a humble representative of the trade, to thank Mr. Dyer for his learned paper which was full of most valuable information and would be closely studied by the rubber manufacturers.

As one who had come into contact with the Government officials, he would like to remark how very anxious they were to help the manufacturers now that they had more time than they had during the war. The manufacturers appreciate the ready help they were always willing to give them.

The Chairman invited other members to contribute remarks in writing, announced that the Author would reply to the discussion in the Journal, and proposed a vote of thanks for the paper.

SUMMARY OF POINTS RAISED IN A WRITTEN COMMUNICATION FROM MR. A. D. RITCHIE, FORMERLY CHIEF AIRSHIP CHEMIST.

1. Avorio considers the dimensional effect observed by him to be due to seams. Bursting tests on envelopes point to some, and possibly an important, weakening due to seams.

2. The bursting tests at Kingsnorth were done with a rate of loading less than 30lbs./in/min.; at least 10 minutes were taken to reach bursting pressure.

3. Considerable weight, in my opinion, is to be attached to the statistical evidence as to the relation of weight and permeability.

(i.) It is shown clearly that results with one specification are very variable, so that comparisons of specifications based on a few tests are misleading.

(ii.) As against the argument that the apparent similarity of permeability for different weights is due to different degrees of care in manufacture, I should suggest that a bad maker will always get many high permeabilities with light proofings because they are harder to make, and it is only good and uniform workmanship that will show the similarity. At any rate, the following facts must be taken into consideration:—

(*a*) For some time permeability was not specified by the Admiralty; there was only a general clause about workmanship in the contract.

(*b*) The firm worst for permeability was best for regularity of weight (*i.e.*, careful spreading).

(*c*) The minimum permeability (4 litres) was strikingly regular for all makers and all specifications.

(*d*) Consideration of results for one specification showed no correlation between variations of weight and variations of permeability.

(*e*) Some fabrics with as little as 50 gms/m^2 between plies had good permeability.

Owing to the nature of the fabrics made there were no sufficient means to distinguish effects due to variations in weights of a single layer of proofing from those due to variations in number of layers or situation (*i.e.*, between plies or on face).

4. Is loss of sulphur on weathering due to volatilisation?

5. Impregnation of the cotton with rubber would largely prevent seam leakage, but the practical difficulties of impregnations are enormous.

6. Do the Germans soften their goldbeaters skin with glycerine? Do they use Lecithin as I suspected?

P. M. Matthew (communicated): The three questions of chief interest to proofers at the present time are :—

(1) The durability of proofing under tropical conditions.
(2) Its protective action on the cotton fabric.
(3) The efficiency of the seams in the various fabrics.

As the result of experience at home and in France during the past eight years in connection with balloon and airship fabrics, and during the past forty years in the Tropics with waterproof fabrics, I have no hesitation in coming to the conclusion that durability is largely, if not entirely, a matter of vulcanisation, the best method and "optimum degree" of which have yet to be determined.

Perfect vulvanisation, or "optimum cure" as it has been called, is generally understood to mean the production in rubber of its maximum resiliency and tensile strength. While it cannot be said that this is in inverse ratio to its durability under severe weathering conditions, I incline to the belief that something of the kind is the case. In saying so, I have in mind the result of a series of "weathering" tests made during the summers of 1917 and 1918 with various proofings made—

(1) With pure unvulcanised rubber.
(2) With rubber vulcanised to various degrees.
(3) With unvulcanised (but vulcanisable) rubber.

As regards the best system of vulcanisation, which is perhaps still an open question, I incline very strongly to dry heat for gas proofing. I notice you speak of finding a deposit of sulphur in the cotton of certain proofed fabrics. I think you will find it generally present in those which have been vulcanised by moist heat, in which the nature of the process prevents its escape.

As regards the various forms of protective coating on the outer surface of the fabrics, it would appear that so far a suitable combination of rubber and aluminium is the most effective. Here again the "optimum degree" of vulcanisation plays a highly important part in the matter of durability and incidentally, of course, in fixing the aluminium. I may mention that in the case of our samples (spec. No. 23 and 32) now being tested in Egypt, a red dye soluble in rubber is incorporated in the aluminium mixing, no dye being used in the cotton.

Your remarks on the subject of seams are extremely interesting, and all the observations which I made, both in this country and in France during the war, point to defective seams as the chief source of leakage in kite balloons.

By the omission of stitching this would be greatly reduced, as also the risk of damage to the fabric in making up. It has always appeared to me as the result of experience in cognate manufacture that with a gastight inner facing of rubber on the fabric, and tape with a similar weight of facing, it should be possible to make a perfect seam; and at the same time to reduce the width of the tape now in use.

With regard to gasbags for rigids, it is interesting to note that their life is that of the skin lining, and that this is probably lengthened by the use of rubber in place of glue as an adhesive. Is it possible that the trouble caused by the unequal shrinkage of the cotton fabric and the skins would be lessened were the uniting solution vulcanised? It would almost seem that were this possible it would reduce the tendency of the two to separate. It seems possible that if the cotton fabric were well stretched in scouring and finishing (though not so as to unduly reduce its strength) it might to some extent contract again with the shrinkage of the skins. The drying-up and loss of pliability in the skins is presumably due to decomposition or dessication of the animal matter. Could this be retarded by applying some antiseptic or preservative along with the glycerine?

I trust you will pardon my troubling you with a rather long letter dictated by interest in your work, and your very wise suggestion that the problems in hand call for empirical as well as scientific methods of treatment.

REPLY TO POINTS RAISED IN THE DISCUSSION.

I do not think there are any figures on the subject of three-ply fabrics referred to by Mr. Campbell. If it is desired to reduce the weight of the middle (bias) ply of a three-ply fabric it will be necessary to consider what degree of protection from tearing is to be provided.

I agree with Dr. Barr that extensibility is important, but so far as I know it has scarcely been studied. Different pieces of fabric by the same maker have different extensibilities for low loads such as are met with in practice. In sustained load tests partial loss of adhesion of plies may be operative, but the tests on single ply fabrics (linen in Table VII. and cotton in Table VI.) show that there is an effect independent of this ply separation. Dr. Barr's correction as to the inferences from Aston's experiments is accepted. My statement needed amplification. Dyes for protection of cotton with the aluminium facing as well have not, I think, been tried. Of the much lowered permeability as reported by Bureau of Standards I have met one case. Unfortunately I had very little of the material. The rubber was unoxidised but very soft.

Major Richmond refers to a subject of great interest and greater difficulty, viz., the mechanism of permeability. It is clear that the difference between gases in respect of this property are not explicable on any of the recognised characteristics of their molecules, but that a reaction, or perhaps better, a transaction, with the substance of the permeable film is also concerned in the total effect. With regard to prevention of superheating and the use of zinc-white or aluminium, I think a knowledge of the nature of the aluminium surface and of the aluminium powder used is very important for the comparison. Figures have been given for aluminium and zinc white reversing the order of efficiency stated by Major Richmond, and further trials may be necessary.

Wing Commander Cave-Browne-Cave refers to the desirability of a list of references to original papers. One that had been prepared is appended. It is not so complete as one would wish. A large amount of the work on non-rigid fabrics is contained only in departmental report principally from Kingsnorth and Manchester and few of these were published by the A.C.A. The same is true of work on skin-lined fabrics and outer covers. With the exception of three or

four papers therefore the bibliography largely refers to work done for aeroplane fabrics, but having either a general or particular bearing on some problem of airship fabrics.

With regard to the points raised by Mr. Ritchie :—(2) If the comparison tensile test had been done at an equivalent rate of loading the ratios T_b/T_t would have higher than those given.

(3) Possibly I gave the statistical evidence on the weight-permeability relation less than its deserts, but that is not to be regretted since it has called forth such a clear statement of the case from Mr. Ritchie. These points have to be taken seriously into account, though I still think the question not proven. Comment must be limited, but the reasons for failure to carry conviction to my mind are briefly :—

(1) There are few or no data on the weight-permeability relation for a single layer of proofing covering a reasonably wide range of weights.

(2) There are such data (not very numerous it is true) for films and sheets of rubber, and a roughly linear relation between weight and reciprocal of permeability has been stated, although various methods of preparation of film and sheet were involved. Further data of this kind should be obtained to place the matter beyond doubt.

(3) With regard to workmanship I should compare not so much one firm with another, but the same firm (*i.e.*, very likely the same workman) at work on light and then on heavy proofings. Long practice in the art probably enables the spreader to boil it down to "much rubber, less care; little rubber, more care." I do not assert that this is the case, but only that it is a possible explanation.

(4) I think sulphur may be, and probably is, lost by volatilisation on exposure, but that oxidation takes place as well and may predominate. My reasons are (i) that in a fabric exposed from January to June the rate of loss was no higher in the hot weather than in the cold; and (ii) that from a fabric kept during three months in a room always warm and for eight hours of the day at 40° C. the loss was less than from a piece of the same fabric exposed to the weather.

(5) I agree that impregnation of the cotton in the full sense of the term is impracticable. What was meant in the paper was the filling of interstices between the yarns. It was suggested by proofers that this might be an improvement. The full test has not yet been carried out, but a stitched seam made in a piece of two-ply D fabric, where the interply rubber had for some reason unknown been very thoroughly pressed into the cloth, gave a very much lower seam permeability than is usual with stitched seams in unfaced fabrics, though presumably this was not for the cause which might be expected to operate in a genuinely impregnated cotton.

(6) Yes, glycerine is used in German skin-lined fabric. No further search for lecithin has been made.

Mr. Matthew's remarks on the importance of correct vulcanisation are interesting, and I should like to read a full account of the experiments to which he refers, because it is a subject on which nothing seems to have been published where maintenance of gas tightness is the principal property under consideration.

There appears to be no doubt that an inner facing of rubber is highly beneficial in securing gas-tight seams, where stitched seams are concerned.

My remarks on rubber versus glue for skin adhesive were meant to favour the latter, and experiments on most examples of the two types support my argument. A vulcanised rubber as adhesive should certainly be tried.

The desiccation of the skins on exposure in hot climates seems to reach a

point at which pliability cannot be restored by fresh treatment with glycerine. Whether this is animal decay or attack by decomposition products of the rubber adhesive and proofing does not seem clear.

BIBLIOGRAPHY.

In an account, such as the foregoing, which is principally a description of broad results based on much detailed experiment it merely confuses to refer to individual original papers pertinent to the subject under discussion at the moment. A list of the more important papers is therefore appended, roughly classified. On some important matters there are no published reports available, the only papers being confidential official ones.

The classification of the bibliography does not follow the divisions used in the body of the report. It is sufficiently indicated by the sub-headings.

The letters T. and R. and M. are references to the well known A.C.A. reports.

Strength (new fabrics).
T. 1204.
R. and M. 23, 29, 37, 180, 182.
Strength (effect of light, acidity).
T. 1019, 1381.
R. and M. 430, 585.
Permeability.
T. 998, 1124, 1197, 1224.
R. and M. 22, 232, 317, 360, 435, 447, 513, 584.
Weathering (non-rigid fabrics).
T. 602, 602a, 900, 1157.
R. and M. 313.
Dopes. Material (including solvents).
T. 816, 1269, 1412, 1502, 1550.
Tautness.
T. 1193.
R. and M. 569, 606.
Radiation and superheating.
T. 993.
R. and M. 329.

Bureau of Standards, technologic paper No. 128.

RIGID AIRSHIPS.

Two Lectures delivered by J. L. Bartlett.

LECTURE I.

Introduction.

In this lecture it is proposed to deal with the general aerostatical principles governing the flight of lighter-than-air craft, and also to describe briefly the various types of airships, with special reference to the rigid airship.

The future of lighter-than-air craft is undoubtedly dependent upon the development of the rigid airship, in which type of ship efficiency and performance increase at a greater rate than the gross lifting capacity.

To understand the working of a large airship it is essential to have a thorough grasp of the elementary aerostatic principles governing the flight of an ordinary free balloon, so it is proposed, first, to outline these principles and then to pass on to the non-rigid, semi-rigid and rigid types of airships, all of which are virtually balloons of varying type, rendered dirigible by the fitting of means of propulsion, and navigable by the introduction of controlling surfaces.

Aerostatical Principles.

All lighter-than-air craft depend for their lifting power on the displacement of air by a gas lighter than air. All gases lighter than air will give a lifting effect in air, but the maximum effect will naturally be obtained when hydrogen, the lightest known gas, is used.

Pure hydrogen at a temperature of 60°F. and barometric pressure of 30 inches weighs 5.33lbs. per 1,000 cubic feet.

Dry air at the same temperature and pressure weighs 76.59lbs. per 1,000 cubic feet.

Therefore in a balloon inflated with pure hydrogen, the gross lift at the above temperature and pressure would be 71.26lbs. for each 1,000 cubic feet of hydrogen that the balloon contains.

Small changes of pressure and temperature have a considerable effect upon the lift of hydrogen, *e.g.*, the figure of 71.26lbs. at 60°F., 30in. pressure, is reduced to 66.58lbs. per 1,000 cubic feet when the barometer pressure is 29in. and the temperature is 70°F.

The hygrometric state of the atmosphere also affects the lift. The effect is relatively small, but is always allowed for in the accurate determination of the lift of a ship. Damp air is lighter than dry air, therefore our lift is always decreased on account of dampness. The decrease rarely exceeds .30lbs. per 1,000 cubic feet.

It becomes expedient for the purposes of design and comparison to adopt some standard of temperature and pressure, or what amounts to the same thing, to adopt a standard of lift per 1,000 cubic feet of hydrogen, and the *standard condition* taken in this country is a lift of 68lbs. per 1,000 cubic feet.

Hydrogen used in a balloon or airship is not pure, and the impurities consist mainly of air. Hydrogen for inflating purposes can be produced at about 97 or 98 per cent. purity.

In the experimental determination of the actual lift of an airship the hydrogen purity is measured and an allowance made. If the purity of the hydrogen were

97 per cent. our lift of 71.26 lbs. per 1,000 cubic feet at 60°F. and 30in. barometer would become 97 per cent. of 71.26, which equals 69.12.

As a balloon rises the gas with which it is inflated expands. This is due to the fall of pressure exerted by the external atmosphere. If the neck at the bottom of the balloon is open, gas will be continually escaping as the balloon rises, the balloon however remaining full, the gas merely becoming less dense. The temperature also falls as the altitude increases. Fig. 1 shows curves of the variations

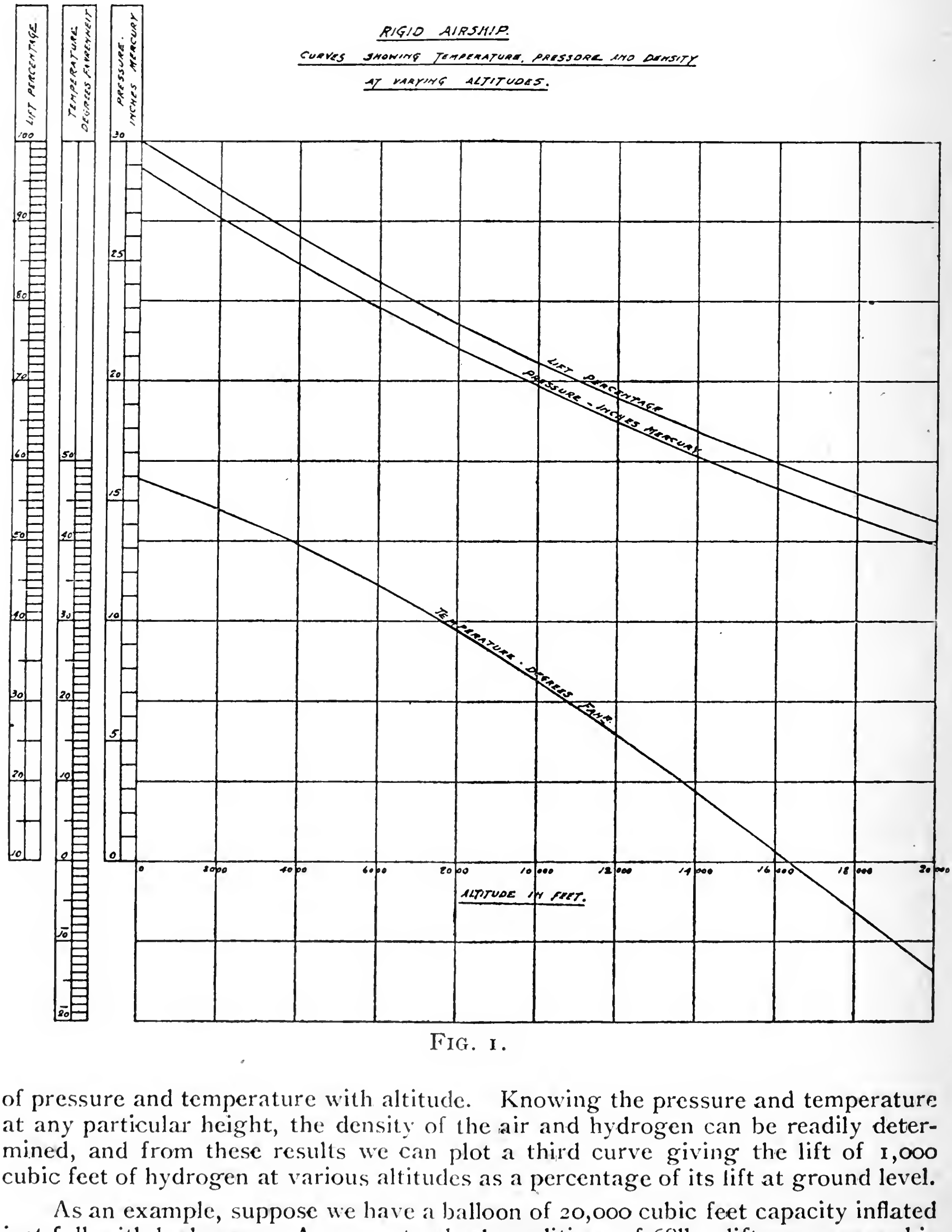


FIG. 1.

of pressure and temperature with altitude. Knowing the pressure and temperature at any particular height, the density of the air and hydrogen can be readily determined, and from these results we can plot a third curve giving the lift of 1,000 cubic feet of hydrogen at various altitudes as a percentage of its lift at ground level.

As an example, suppose we have a balloon of 20,000 cubic feet capacity inflated just full with hydrogen. Assume standard conditions of 68lbs. lift per 1,000 cubic

feet, and suppose that the balloon weighs 300lbs. and men 320lbs., that is, our total fixed weight is 620lbs.

Our gross lift is 20 × 68	... ...	=	1,360lbs.
Our fixed weight ...	... ...	=	620lbs.
Therefore the ballast required will be	... ...		740lbs.

As ballast is thrown out the balloon will rise. From the percentage lift curve we find that at 8,000ft. our gross lift is $77\frac{1}{2}$ per cent. of what it is on the ground, therefore in order to reach 8,000 feet the amount of ballast discharged will have to be $22\frac{1}{2}$ per cent. of 1,360lbs. (our gross lift), *i.e.*, 306lbs. of ballast will have been thrown out. The balloon will still be just full.

Let us trace the descent from 8,000ft. To start the descent, a little gas must be let out through a valve at the top of the balloon. Suppose the balloon is now about 5lbs. heavy, it will begin to fall slowly. As it falls the atmospheric pressure increases and the gas contracts in volume. There is now a definite mass of gas in the balloon, and this displaces a definite mass of air. Therefore, irrespective of the volume occupied by the gas, the effective lift remains the same throughout the descent provided the temperatures of the hydrogen and the air are the same. So theoretically our balloon will reach the ground 5lbs. heavy.

In practice, however, it will be found that if a balloon is allowed to fall unchecked, a comparatively heavy expenditure of ballast will be required to bring her to rest. This is due mainly to the fact that the gas does not readily take up the temperature of the surrounding atmosphere. The ballast reserved for checking the descent of a balloon or airship is known as "landing ballast."

Reverting to our balloon of 1,360lbs. gross lift and 620lbs. fixed weight, we have seen that 306lbs. of discharged ballast corresponds to about 8,000ft. altitude. Clearly, instead of losing gas and ballast during the ascent, the same altitude could be reached by inflating only 80 per cent. full, *i.e.*, saving 4,000 cubic feet of hydrogen and carrying 4 × 68lbs. = 272lbs. less ballast. The balloon would now be balanced on the ground with a

Gross lift 16 × 68 ...	... ...	=	1088lbs.	
Fixed weights (as before) ...	... ...		620lbs.	
	Ballast		468lbs.	instead of 740.

We should now reach 8,000ft. with the discharge of 34lbs. of ballast, the gas expanding as the balloon rises, and at about 8,000ft. the balloon will be in exactly the same condition as when she started fully inflated. Therefore, provided a balloon will lift all that is required for the flight and the landing, there is no need for it to be fully inflated. The height to which such a balloon can go before any gas escapes at the neck is referred to as the pressure height.

In a rigid airship automatic gas valves correspond to the neck of a balloon, and when the pressure height is reached, hydrogen escapes through these valves.

At any height below the pressure height an airship can manœuvre without loss of gas. If a ship rises above the pressure height, gas escapes and we get a new pressure height corresponding to the maximum height to which the ship has gone.

The foregoing remarks outline the general principles governing the flight of a balloon, and apply to all types of airships.

It is now proposed to describe briefly the various distinctive types of airships —non-rigid, semi-rigid and rigid.

Non-Rigid Airship.

A non-rigid airship is one in which the shape of the envelope is maintained solely by the internal pressure of the contained hydrogen. It is virtually a balloon with a power unit suspended, the envelope being streamlined in shape in order to reduce head resistance.

In order to maintain the hydrogen pressure during the descent of a non-rigid airship, air ballonets are fitted inside the envelope so that air at a pressure occupies the space of the hydrogen lost during the ascent.

The ballonets may be inflated by means of a blower driven from the power car or by means of an air duct led away from the propeller slip stream.

If the ballonets are empty on leaving the ground, they would remain so throughout the ascent. The hydrogen would be at a pressure sufficient to preserve the shape of the envelope. The automatic gas valve, which is virtually a safety valve, would be set so as to release hydrogen when the pressure becomes about 30 m/m. of water above the atmospheric pressure. Hydrogen, of course, escapes through the valve during the ascent as in the case of a balloon, but the internal pressure is maintained at 30 m/m. above the pressure of the external atmosphere.

On descending the gas contracts and the ballonets come into operation. The ballonets are fitted with automatic valves set to work at a lower pressure than the gas valves. This arrangement prevents gas being forced out when the ballonets are inflated, and it also ensures that air and not hydrogen is expelled, should it become necessary to ascend after descending. This setting of valves ensures that the ship can operate below her pressure height without loss of gas, as in the case of a balloon.

The capacity of the ballonets is dependent on the maximum height to which the airship is designed to ascend. The capacity must be sufficient to fill the space of the hydrogen lost during ascent.

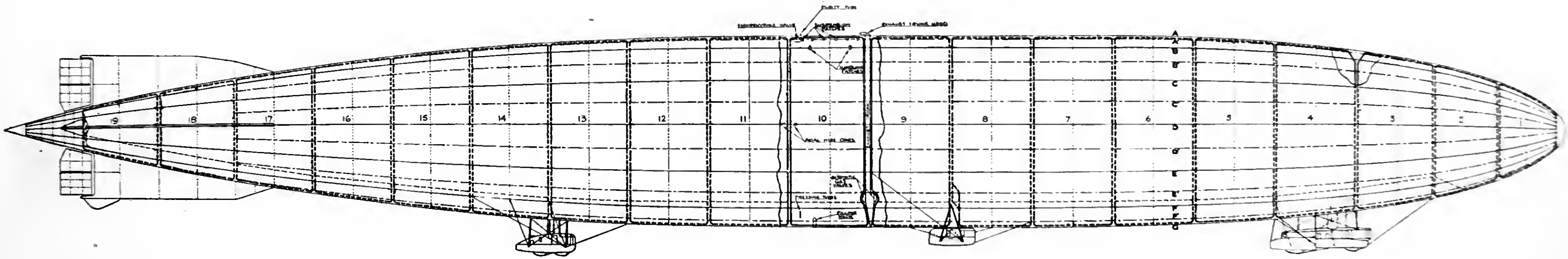
We have seen that a balloon at 8,000ft. has lost $22\frac{1}{2}$ per cent. of its gross lifting capacity, this percentage being deduced from the percentage lift curve at varying altitudes. In a non-rigid airship this $22\frac{1}{2}$ per cent. represents the minimum capacity of the ballonets corresponding to a maximum height of 8,000ft. After descending from such a height the ballonets would be just full.

Semi-Rigid Airship.

A semi-rigid airship is one in which the longitudinal strains are taken by a specially built girder fitted along the underside of the envelope. The envelope pressures can by this means be reduced as compared with those for a non-rigid airship, and this admits the use of a lighter fabric. This saving in weight of fabric compensates partially, or perhaps completely, for the weight of the girder introduced. The semi-rigid type of design due to the introduction of a longitudinal girder lends itself conveniently to the adoption of some rigid support to the bow. It also enables the fins, rudders and elevators at the after end to be more rigidly supported than in the case of the non-rigid ship. Some very successful types of semi-rigid airship have been produced by the Italians.

Rigid Airship.

It is now proposed to describe rather more fully the rigid airship. Non-rigid and semi-rigid airship designs have distinct limits to their cubic capacities. With a rigid airship we have quite a different proposition, and the limit to capacity has certainly not yet been reached; in fact, it is difficult to say what will eventually be the limiting factor in the design of a rigid airship as the gross capacity is increased.



AIRSHIP LONGITUDINAL SECTION

Non-Rigid Airship.

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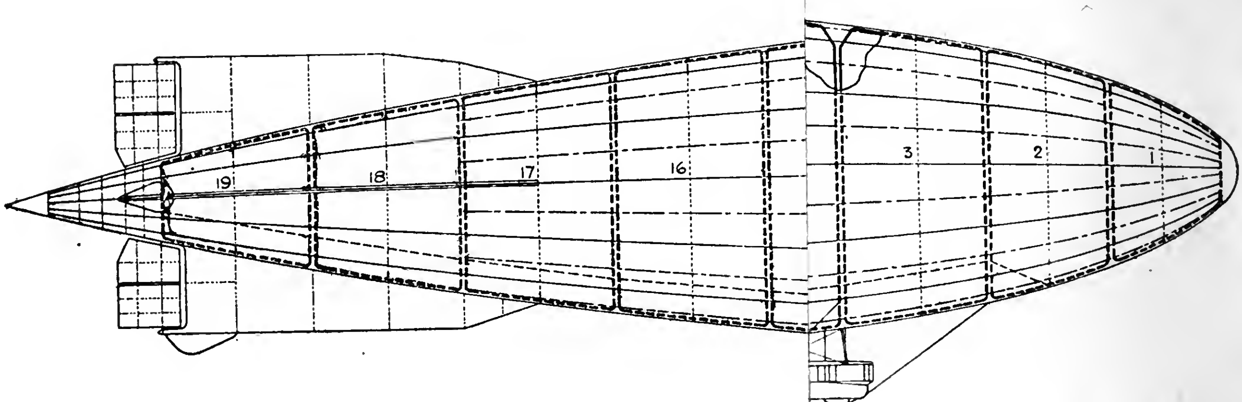

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Rigid Airship.

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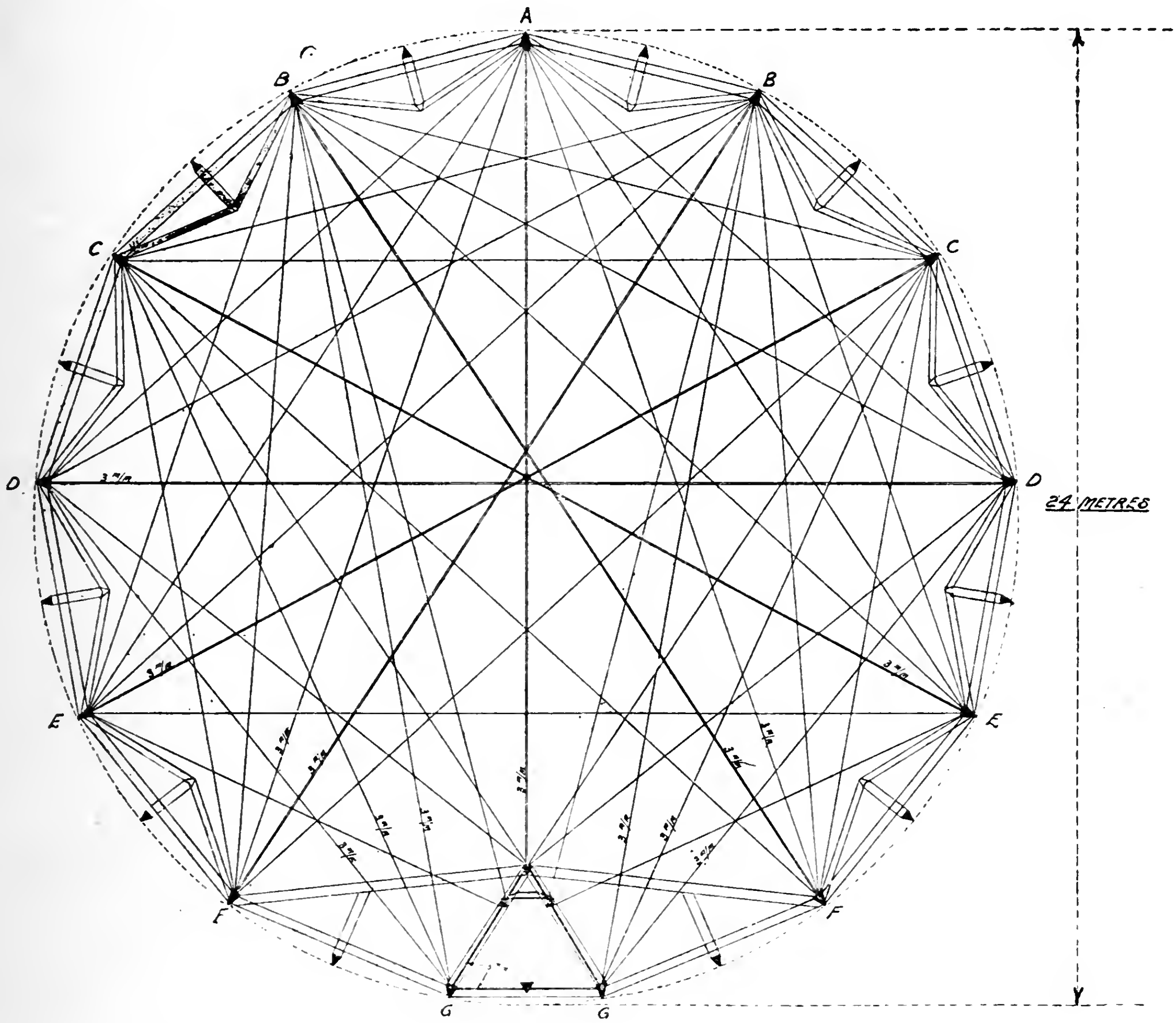
The rigid airship consists of a hull framework that is designed to take all the bending moments and shearing forces that arise. The hull framework encloses the gasbags, the whole being enclosed by an outer cover which is supported by the girder work and the wiring of the hull.

The gasbags and outer cover play no part in the designed structural strength of the ship. The gasbags are merely containers for hydrogen, and are made of very light fabric rendered as gastight as possible by means of a lining of goldbeaters' skins. The gasbags, owing to their lightness, have to be carefully supported by means of wiring or netting.

The outer cover similarly is a relatively light fabric, its function being to give a fair outer surface and to protect the gasbags from exposure.



SECTION MAIN FRAME

FIG. 2.

H.M. Airship R.34 might be taken as being typical of a modern rigid airship, and the principal dimensions of this ship are as follows:—

Capacity	2,000,000 (approx.) cub. ft., which corresponds to—
Gross lift	60 tons.
Fixed weight	About 31 tons.
Useful lift	About 29 tons.
Overall length	645 feet.
Maximum diameter ...	78ft. 9in.

The hull consists of 19 main transverse frames spaced generally 10 metres apart. Those amidships are shaped as polygons of 25 sides, and have a circumscribing circle of 78ft. 9in. diameter.

There are 13 main longitudinals and 12 intermediate longitudinals connecting the main transverse frames. These 25 longitudinals form the edges of the 25-sided polygonal form. Between two consecutive main transverse frames there is a 25-sided intermediate transverse frame.

Main transverse frames are wired in their plane in order to preserve transverse rigidity. The gasbags, of which there are 18, fill the spaces between the 19 main frames.

The panels of the outer surface of the hull formed by the longitudinal and transverse girders are cross-braced with the two distinct systems of wiring known as

(*a*) Major diagonal wiring.
(*b*) Minor diagonal wiring.

Inside the hull built up from the two bottom longitudinals is a corridor running practically the whole length of the ship. This corridor serves as a gangway for the purpose of getting from one car to another, or to any desired part of the ship. The corridor also serves as a longitudinal girder for the carrying of petrol tanks and water ballast bags, which are distributed throughout the length of the ship.

The corridor girder is supported at each main transverse frame by wires leading to the top of the ship. In this way the local loads to which the corridor is subjected are distributed to the various main joints in the upper parts of the hull structure.

At the after end of the hull structure horizontal and vertical fins are fitted in order to stabilise the motion along the longitudinal axis. At the after end of each fin is a rudder or elevator plane operated mechanically from the forward control car. By means of these planes the ship can be manœuvred. The fins, rudders and elevators are built up of girders, the surfaces being covered with outer cover fabric.

Girders.

The girders comprising the hull structure are of various types and sizes depending, of course, on the particular work for which they are designed. Generally they are triangular in section and formed by longitudinal duralumin channels at the three corners of the section, each face of the girder being cross-braced by means of light duralumin stampings. A relatively strong girder per lb. of weight can be obtained in this manner.

Duralumin.

Duralumin is used generally for the hull structural work, and this material is an alloy of aluminium, its composition being :—

Aluminium			94%
Copper			4—4½%
Magnesium	.65	1½—2%	
Manganese	.50		
Silicon	.50		
Iron	.30		

Its S.G. is 2.79, which gives it a weight of .102lbs. per cubic inch. Its melting point is 650°C., and its coefficient of linear expansion is .0000226.

It has an ultimate tensile strength of about 25 tons per square inch with an elongation of 20% in 2in. The elastic limit is about 14 tons per square inch. It can be manufactured up to 35 tons per square inch with very little elongation.

Young's modulus (E) for duralumin is about 4,700 tons per square inch. The yield point in tension is about 20 tons per square inch and in compression about 10 tons per square inch. In compression duralumin is weight for weight approximately of the same strength as steel.

Gasbags.

Gasbags are made of skin-lined rubber-proofed cotton fabric. The plain cotton fabric weighs 65 grams per square metre, and has a rubber proofing of 20 grams per square metre on one face. This face is lined with goldbeaters' skins, these being light strong skins highly impermeable to the diffusion of hydrogen. The finished weight of the skin-lined fabric is about 150 grams per square metre.

Each gasbag is fitted with an automatic gas valve at or near the bottom of the bag, and for the parallel portion of the ship this valve is set to blow at a gas pressure at the bottom of the bag of 5 m/m. of water in excess of atmospheric pressure. This pressure, it will be realised, is a very low one. It corresponds to .0071lbs. per square inch or approximately 1 lb. per square foot.

A gasbag fitted in the parallel portion of R.34 is about 24 metres, *i.e.*, approximately 78ft. in diameter and with 5 m/m. of water pressure at bottom of such a bag, the excess pressure at the top due to the differences in density of air and hydrogen would be 31 m/m., or approximately $6\frac{1}{4}$lbs. per square foot. Very approximately the pressure in a gasbag increases 1 m/m. of water for each metre of vertical distance.

It will be observed that although these pressures are small when compared with atmospheric pressure, the areas subjected to these gas pressures are relatively large. Naturally, if we integrate the upward excess pressures we get the gross lift of the airship, which in the one described amounts to 60 tons.

The area of the transverse end of a gasbag in the parallel portion is about 4,800 square feet, and if we take a pressure of 5 m/m. at the bottom, the average pressure over the end is about 18 m/m. of water, which corresponds to a total end pressure of nearly 8 tons. With a neighbouring gasbag deflated, or partially deflated, the supporting of this end pressure becomes a most serious problem, on which it is proposed to remark further in the second lecture.

At the ends of the ship the gasbags are naturally smaller in diameter, and the automatic gas valves are set to correspond to a higher pressure at the bottom of the bag. If the setting of automatic gas valves corresponds to the actual heights of the various valves above a level line, then it is clear that at the pressure height gas would be blowing from all bags simultaneously.

Top or manœuvring gas valves are fitted to about one half of the total number of bags and are operated from the control position. These valves correspond to the top valve in a balloon and enable the equilibrium and trim to be adjusted should the ship become light due to the consumption of petrol and oil.

Outer Covers.

The outer cover is made up in panels of doped linen or cotton, the separate panels being stretched tightly and laced to the main girders of the hull. The fabric is usually doped before being made up into panels, and the completed outer cover is finally doped in place at the ship. The function of the dope is to preserve watertightness, and the coating in place assists the tautening of the cover.

The outer cover must be attached wherever possible to the various diagonal wires by means of lacing strips fixed to the inner surface of the fabric.

The finished outer cover weighs about 140 grams per square metre.

The outer cover of an airship has several important functions. It has to be taut in order to give a fair outer form. If the cover is slack it begins to flap during flight and this appreciably increases head resistance. The cover also must be well doped as otherwise the amount of moisture absorbed by the fabric will be considerable. The cover, too, must protect the gasbags from superheating, *i.e.*, it must reflect the heat rays, and to meet this requirement aluminium powder is usually mixed with the final coating of dope.

Special care is taken to provide extra support for the outer cover in wake of the propellers.

Machinery.

The power units are located in cars that are suspended below the ship at various points. Airship R.34, of which the dimensions have been given, has four power cars—one forward, two amidships and one aft. The after car contains two 250 h.p. engines geared to drive one propeller. The other power cars each contain one 250 h.p. engine. The two wing car units are fitted with reverse gearing. Petrol is supplied to the power cars from service tanks carried in the corridor.

General.

The ship is navigated from a control car forward and from the control position, engine telegraphs and telephones are arranged to all power cars.

The rudders and elevators are operated from the control car, and auxiliary operating positions for these main controls are provided in the after power car.

The top gas valves and the water ballast valves are also controlled from the navigating position. The ordinary water ballast is carried in fabric bags, each containing about one ton of water, and from each bag water can be discharged at the rate of about 1½ gallons per second. At positions forward and aft, emergency water ballast bags are provided, and these are fitted with special release arrangements that enable about one ton of water to be discharged from each position in a very few seconds. This emergency water is usually reserved for landing, should a ship have an excess of downward momentum when near the ground.

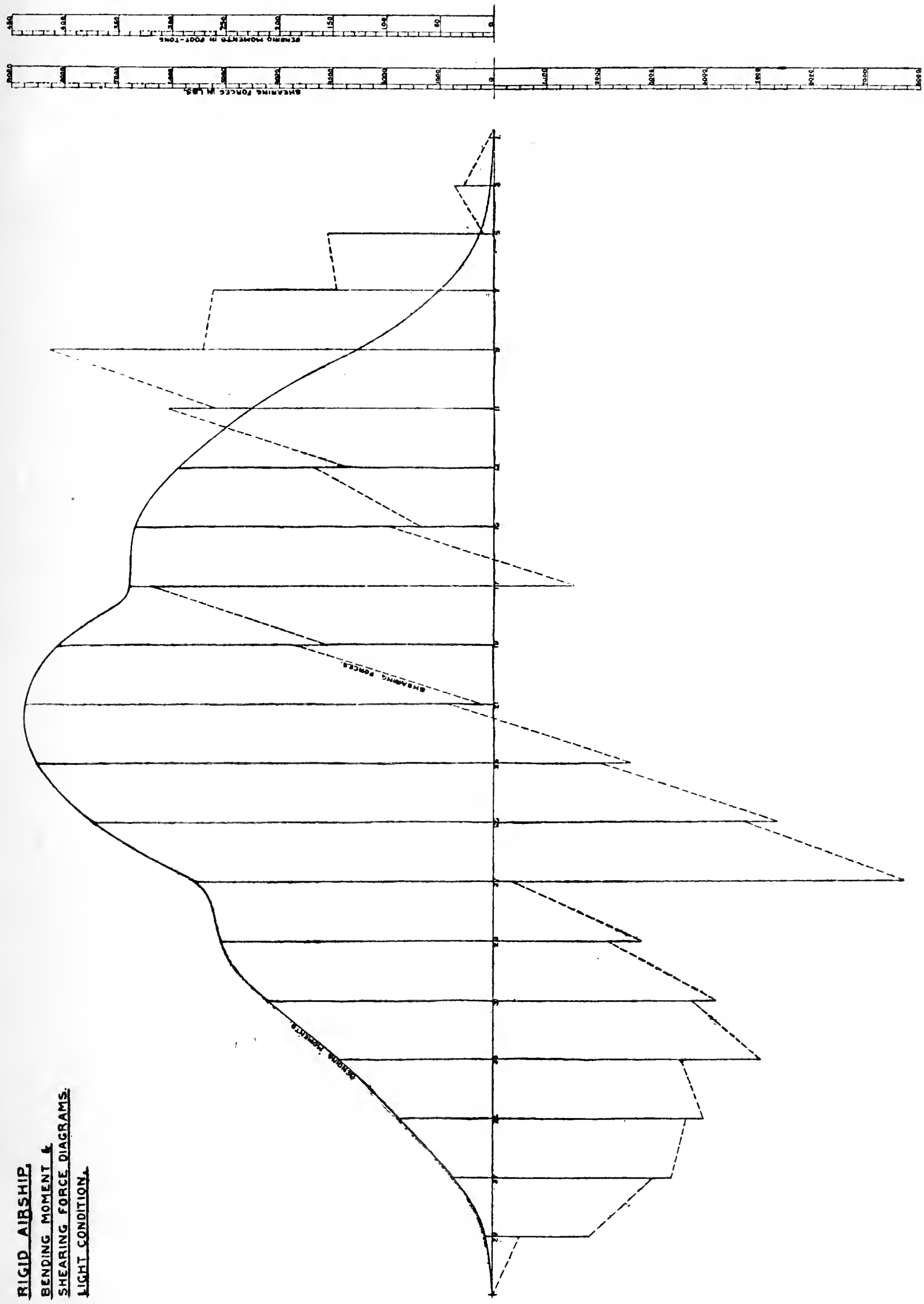
This concludes the general description of a modern rigid airship, and in the second lecture it is proposed to examine some of the more important features connected with the design of such a ship.

LECTURE II.

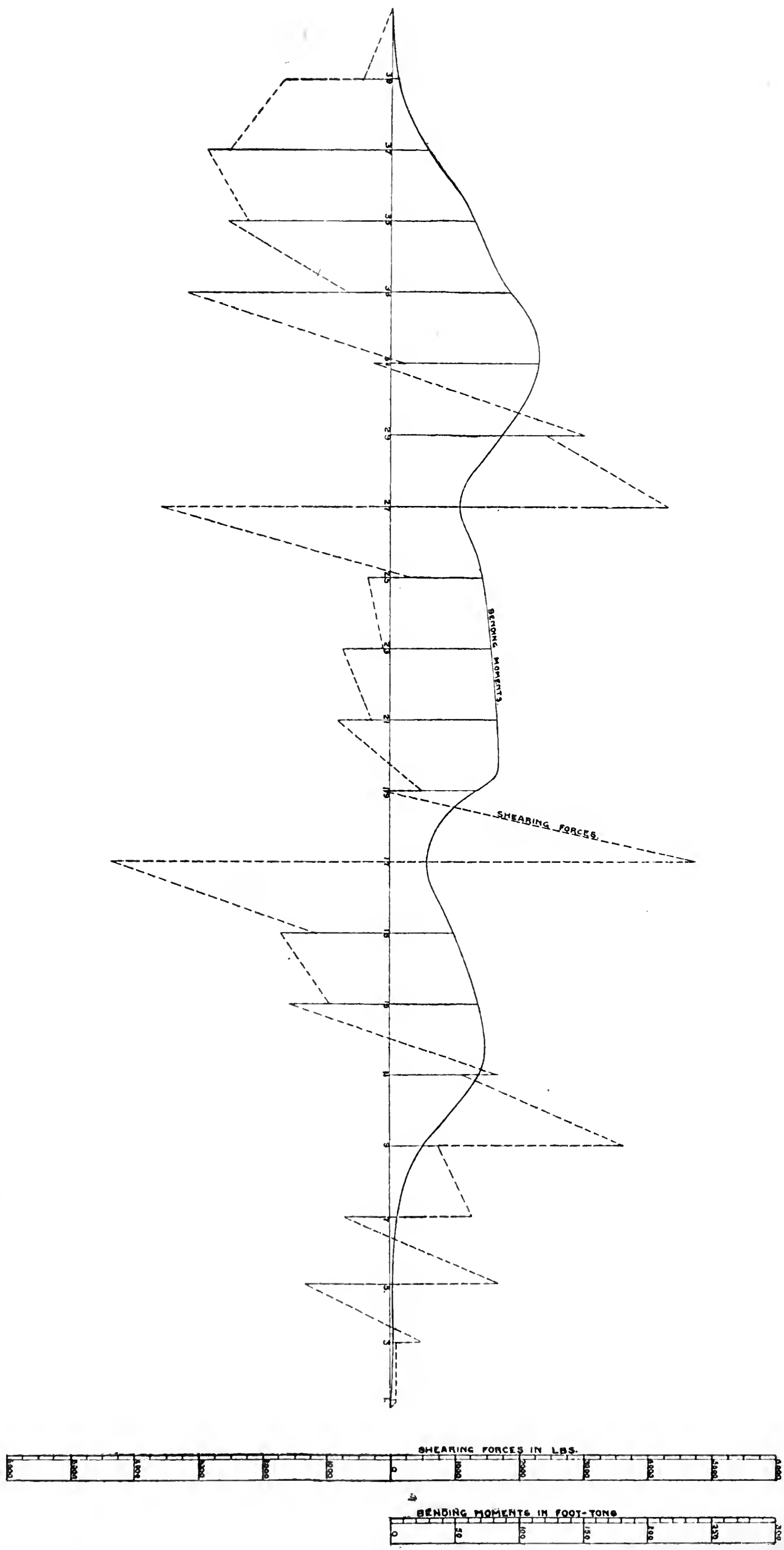
Introduction.

In this lecture it is proposed to refer to some of the more important problems that have to be considered in the design of a rigid airship. A designer might be limited to size by considerations of first cost or the dimensions of sheds available. His problem is to produce for any given gross capacity the largest possible useful lift without sacrificing the structural strength necessary for airworthiness and to provide for a reasonable air speed to enable the ship to make headway against winds that are likely to be encountered.

We have seen in the first lecture that a ship of two million cubic feet capacity has a gross lift of about 60 tons, and that with such a gross capacity the length is 645ft. and the diameter 78ft. 9in. The designer's problem is to provide a structure of these dimensions capable of resisting all the strains to which it might be subjected, to fit machinery capable of propelling it through the air at about 60 miles per hour, to fit gasbags, outer cover, petrol system, control arrangements



RIGID AIRSHIP.
BENDING MOMENT &
SHEARING FORCE DIAGRAMS.
LIGHT CONDITION.


BENDING MOMENTS
SHEARING FORCES
SHEARING FORCES IN LBS.
BENDING MOMENTS IN FOOT-TONS

and equipment, using as little as possible of the 60 tons of gross lift, the usefulness of the completed article depending mainly on the amount of the 60 tons available after all the above requirements have been fulfilled. An airship designer, therefore, has to be particularly careful to economise weight in every detail and to see that as far as possible every pound of weight worked into the hull structure contributes to the strength of the ship.

Stresses to which the Hull Structure is subjected.

With these preliminary remarks we will proceed to consider generally the stresses to which the hull of a rigid airship is subjected.

The completed ship might be considered as a girder, and due to the differences in distribution of weight and buoyancy it becomes subjected at each point of its length to a bending moment and a shearing force. The distributions of weight and buoyancy are plotted graphically on a base representing the ship's length, and from these two curves a resultant load distribution curve is deduced. The first integral of the load distribution curve gives a shearing force curve, and the integral of the shearing force curve gives the bending moment curve. From these last two curves we can determine the bending moment and shearing force at any section of the ship. Knowing the bending moment at any section, the stresses in the various longitudinals can be determined from the formula "$p = My/I$," I being the moment of inertia about the neutral axis of all materials in the section that contribute to longitudinal strength.

Such curves as these briefly described are drawn for two main conditions:—

(1) Ship fully loaded and fully inflated, *i.e.*, the heavy condition.

(2) Ship lightened as far as possible by the discharge of all disposable weights except those necessary for landing, the gasbags being correspondingly deflated in order to balance the ship.

The condition that the ship must be floating on an even keel in each of the above cases amounts to saying that the total area of the load distribution curve is zero and the centres of areas of the buoyancy and weight curves are in a line at right angles to the base.

Bending moment and shearing force curves * for a modern rigid airship in the heavy and light conditions are shown in Figs. III. and IV.

Distribution of Vertical Shear.

The shearing force at any section in the parallel portion is taken by the diagonal wiring. In this lecture we must confine ourselves to the vertical shearing forces, but it must be borne in mind that considerable shearing forces and bending moments are brought about in a horizontal plane when a ship is turning in the air or being handled on the ground. The greatest proportion of the vertical shearing force at any section of the parallel portion is taken by the diagonal wires nearest to the horizontal plane through the neutral axis.

At the tapered ends of the ship a certain proportion of the vertical shear is taken by the longitudinal girders.

The method of determining the distribution of shearing force at a section in the parallel portion, assuming the simplest case of one system of diagonal wires, is outlined in Appendix I.

By means of the formula $T = \dfrac{FLA \sin \theta}{D\Sigma A \sin^2\theta}$ we can determine in this simple case, the stresses to be borne by the various diagonal wires due to vertical

* Curves taken from Mr. C. J. Campbell's Paper, Transactions, Institute of Naval Architects, 1919, "Development of Airship Construction."

shearing force, and it is on these general lines that the sizes of the wires in the diagonal systems are determined.

One might add that besides drawing curves of bending moment and shearing force for the heavy and light conditions, the designer usually produces a set of curves, assuming each gasbag separately deflated. The deflated bag condition is severe, but as regards longitudinal strength the hull structure is designed to withstand the stresses that would arise as the result of any one bag being totally deflated. The most serious aspect of the deflated bag condition will be referred to later.

Longitudinals with Lateral Load.

So far we have considered the longitudinal girders of the ship only as acting as struts or ties to resist the bending moment across any section. These girders however are also subjected to a lateral load due to the gas pressures, these gas pressures being applied by the gasbags themselves or transmitted to the girders by the gasbag netting. At the top of the ship when the gasbags are fully inflated, *i.e.*, in the heavy condition, these lateral loads are considerable. In the light condition, due to the gasbags being at a less degree of inflation, the lateral loads are relieved to some extent, but as in all conditions the upper longitudinals are subjected to a lateral load, it is most important that the bending moment should be such as to put these longitudinals in tension and not in compression, *i.e.*, the ship should be "hogging" in all conditions. Also as lateral loads are most severe in the heavy condition, the bending moment for that condition should be as small as practicable. Petrol and water ballast in a rigid airship are distributed by the designer so that in the heavy condition the bending moment curve is one of the smallest possible ordinate. The worst bending moments arise in the light or deflated bag conditions, but in these conditions the lateral loads are not so severe. Any excessive bending moment or shearing force in the light condition can only be relieved by a re-arrangement of distribution of fixed weights.

As we have already seen it is desirable to have the ship "hogging" in all conditions. This puts compression on the lower longitudinals of the ship. The condition here, however, is relieved by the fact that the longitudinal structure of the corridor can be arranged to take its proportion of the stresses.

With this brief survey of the method of arriving at bending moments and shearing forces in any condition and the consideration of various loads brought to bear on the girders and the wires due to the longitudinal bending moments, shearing forces, and the gas pressures, we will pass to the consideration of the wiring of a transverse frame, and will discuss the more important stresses to which transverse girders are subjected.

Stresses in Transverse Wiring and Transverse Girders due to Differences in Gas Pressures of Two Consecutive Bags.

Generally, all main transverse frames are wired with a system of radial and chord wires. The main stresses in the transverse frame arise when one gasbag is more fully inflated than its neighbour, the extreme case being when one bag is full and the next one empty. With a deflated bag the whole of the end pressures of the neighbouring gasbags have to be taken primarily by the transverse wiring, and the tensions thus put into these wires are transmitted to the joints causing compression in the girders of the transverse frame. It is the consideration of the deflated bag condition that governs the strengths of the transverse framing and wiring that is required.

Consider a system of radial wiring, *i.e.*, wires coming from a central ring to each of the main joints of the transverse frame. Such a system was fitted in the earlier British rigid airships.

When the end pressure of a gasbag has to be supported by this system of wires clearly the only longitudinal support is the sum of the resolutes of the wire tensions along the longitudinals at each joint.

The more the wires are bulged out the less becomes the angle of the wire at the joint to the longitudinal direction. Thus if wires can be fitted that will stretch sufficiently it becomes practicable to support the gasbag end pressures by virtue of the bulging out of the wires until the sum of the longitudinal components of their tensions balances the gasbag end pressure.

We will now consider for a few moments the mathematical investigation of the transverse wire tensions in the deflated bag condition assuming a perfect radial system of wires. (See Appendix II.)

Examination of the equations arrived at in Appendix II. by taking some concrete cases will demonstrate that with steel wires fitted radially it is virtually impracticable to support the end pressure of a gasbag more than about 50ft. in diameter, the main trouble being the enormous compression thrown on the girders of the main transverse frame. Consequently, with modern airships special means have to be adopted to cope with this problem, and there are two main alternatives that suggest themselves.

(1) The fitting of a longitudinal axial wire, whose function is to restrain the axial movement of the centre ring, *i.e.*, to make $y_0 = O$ in the equations (Appendix II.).

(2) The fitting of wires, that in the event of the whole end pressure having to be supported, would be strained to a point just beyond the elastic limit of the material, at which point the relatively large extension would admit of a considerable axial movement of the centre ring. The effect of this is to confine the wire tensions, and therefore the compressive stresses on the main transverse girders to within reasonable design limits, the longitudinal resolute of the wire tension at the joints being increased due to the more favourable angle that the wire makes with the longitudinal at the joint. For this treatment of the problem, duralumin wires would probably give the best solution, duralumin having a low elastic limit when compared with its yield point or its breaking point.

The first solution has been adopted in British designs for ships of relatively large diameter, the axial wire running longitudinally through all the gasbags and connecting the centre rings of the transverse wiring.

In addition to the pure radial system of wiring, chord wires are introduced, and these serve to break up the otherwise unsupported portions of the gasbag surface.

The horizontal component of the wire tension at the joint is determined by putting $x = r$ in equation (6) (Appendix II.), and this gives $- T\, dy/dx = \frac{2}{3} Kr^3 \tan \alpha + Ty_0/r$, and using this equation in association with curves of T and y we find values that will satisfy the condition of equilibrium, that the sum of longitudinal components of T shall balance the total end pressure of the gasbag.

The mathematical treatment and the formula arrived at apply only to a perfect radial system. The introduction of chord wires must affect our results, as these wires are assisting in the transmission of pull to the joints and their effect is to reduce the tension in the radial system. In consequence, our formulæ give absolute maximum values of the various stresses and are of considerable importance to the designer when used in conjunction with observed wire tensions for various degrees of gasbag inflation. Experiments have frequently been carried out on rigid airships, where isolated gasbags have been inflated, the corresponding wire tensions being recorded. This test is perhaps the most severe structural test to which a rigid airship can be subjected.

With an airship in flight, the excessive strains that would arise should one bag become deflated would be relieved considerably by letting down the neighbouring gasbags so as to distribute the strains equitably amongst 3 or 4 transverse frames.

We have so far outlined some of the main stresses to which the various girders of the hull are subjected. We will now consider for a moment the various types of girders used in R.34 and their functions. We will also discuss the general method of girder design.

Girders.

We have seen that longitudinal girders have to withstand lateral load as well as tension or compression. They are therefore made isosceles in section, and placed apex outwards. The two base channels of the girder resist the compression due to the lateral load, the apex channel being in tension. As duralumin has a yield point in tension of about 20 tons per square inch, and in compression of about 10 tons per square inch, it will readily be seen that the apex out arrangement is the most favourable aspect for equitable stress distribution.

Superimposed on the stresses induced by the lateral load, we have the tension or compression due to the static bending moment that we discussed when we were considering the whole ship as a girder.

When a girder is in tension or subjected to a lateral load, calculations of stresses in the channel members do not present any serious difficulties.

The design of a girder to act as a strut is perhaps best considered in connection with experimental results of tests on duralumin sections.

If a section of duralumin channel or angle be tested in compression, it is found that if L/k is large (say, over 150), the strut fails at loads that very nearly approach those given by Euler's formula $P = \pi^2 EI/L^2$.

At lower values of L/k the crippling stress, as might be expected, falls away from that given by Euler's formula. At certain values of L/k a discontinuity might appear in a curve of failing stress plotted on a base of L/k. This discontinuity is due to failure of the exposed edges of the channel or angle. It has been demonstrated that this secondary flexure can be avoided if the ratio of the thickness to the depth of the flange of the angle or channel is greater than about 1/10. This figure, however, depends to some extent on the actual value of L/k.

Another method of avoiding secondary flexure is to turn in and thus stiffen the exposed lip flanges of the section.

Girders that have to stand pure compression are generally of equilateral triangular section. The main transverse girders are built up of equilateral triangular sectioned girders, kingposted as shown in Fig. V. The kingpost is in the centre of the girder and is attached to the intermediate longitudinal. This arrangement, besides making the girder strong in compression, enables lateral load on intermediate longitudinals to be transmitted through the kingpost trusses to the main joints without causing any serious lateral load on the main compression member of the transverse girder.

In designing a braced girder to act as a strut, the following considerations must be borne in mind :—

(1) Theoretically the strongest strut of any specified length is the one with the largest possible moment of inertia of section.

(2) Expressing the moment of inertia of the section as Ak^2 [area × (radius of gyration)^2], the most efficient method of getting a large moment of inertia is to increase k. The weight of the channel members of a girder of given length varies as A, and therefore for an efficient load per unit weight of channel, A should be small, the inertia being obtained by increasing k.

(3) To avoid secondary flexure there is a practical limit beyond which A cannot be reduced. The flange of the channel must be deep enough to enable bracing pieces to be riveted on to it, and the thickness of the flange must increase with the depth if secondary flexure is to be avoided.

(4) As the strength of struts is a function of L/k, it is clear that the L/k of the small length of channel unsupported by bracings must not be greater than the L/k for the whole girder. Therefore as k for the whole girder increases, the span of the bracing pieces would tend to become less, *i.e.*, the number of bracings increases with an increase of k for the whole girder. Also as k increases the lengths of the bracings increase; hence we may say that approximately the weight of the bracing pieces increases with the k^2 of the girder.

Now our problem is to design a strut of required length that will take the greatest load per unit weight of material. Considerations (1) and (2) above favour a large radius of gyration, whilst (3) and (4) favour a small radius of gyration, so of necessity the result is a compromise, and the most efficient type of strut must be eventually designed from experimental data supplemented as necessary by theoretical considerations.

There are several good formulæ that might be used for comparing the strengths of similar struts, these formulæ of necessity containing experimentally determined constants that allow for the facts that struts are never perfectly straight nor axially loaded; neither is the material homogeneous nor isotropic.

Airship girders have values of L/k generally between 40 and 50, and the total load that the girder will stand in compression might be taken as being 10 tons per square inch of material in the cross section. It must be observed, however, that the best values of L/k and crippling stress vary with different types of girders and can therefore be accurately determined only from experiments on the particular type of girder under consideration.

Perhaps the best method of tabulating the results of strut tests is to plot the crippling stress per unit of sectional area on a base of L/k.

Form and Resistance.

We will now pass on to consider briefly the question of outer form and resistance.

There is no satisfactory method of accurately calculating the resistance of an airship form at various speeds and the designer instinctively turns to the consideration of model experiments. Such experiments are of great value to the naval architect in the determination of the resistances of surface craft.

There are, however, some subtle differences between model experiments as applied to airship resistances and model experiments for the determination of the resistances of surface craft. Naval architects, by measuring the pull necessary to draw a model across a tank, can predict only the wave-making resistances of a ship with any degree of accuracy, and this prediction is based on Froude's law of comparison, which does not apply to surface friction, nor can it be correctly applied to resistance due to eddies.

In an airship we have the case of vessel totally immersed in a fluid, and therefore surface wave-making resistance does not enter into our consideration, the causes of resistance being essentially due to surface friction and eddies.

It therefore becomes necessary before the results of model experiments can be usefully interpreted to develop a law of comparison for the surface frictional and eddy-making resistances of totally immersed similar bodies.

The general formulæ for the resistances of any form moving totally immersed through a fluid and the conditions for similarity of flow around geometrically similar bodies are developed in the manner indicated in Appendix III.

The method adopted at the National Physical Laboratory in order to test an airship form is to measure the resistance of a model in a wind tunnel and to determine the value of the coefficient, C, in the formula $R = \rho C V^2 L^2$ (see Appendix III.) for varying values of VL.

In order to criticise a shape this method gives satisfactory results, but as VL on the model, due to practical limitations, is much less than the VL of the ship, it is of relatively little value as a method of computing the total ship resistance, it not being known how C varies as VL increases. C is really a dimensional function of the variable $\rho VL/U$.

Various shapes have been tested at the N.P.L., and in a most interesting paper on this subject contributed by Mr. Pannell, published in the September issue of the AERONAUTICAL JOURNAL, the following conclusions are arrived at:—

(1) A form of tail $2\frac{1}{2}$ diameters long gives as low a resistance coefficient as any tail yet examined.

(2) A form 4.6 diameters long can be produced which will give a resistance coefficient of .007 at $vl = 60$ feet square per second. (It might be observed here that the similar coefficient for a form such as R.34 is .011 at $vl = 60$.) The forward curved portion of such a body may be elliptical and must be at least two diameters long. There should be no cylindrical portion.

(3) The introduction of cylindrical body generally causes an increase of resistance coefficient at higher values of vl.

(4) In forms of more than one diameter cylindrical body, a tail 2.75 diameters long may be used without appreciable increase in resistance coefficient.

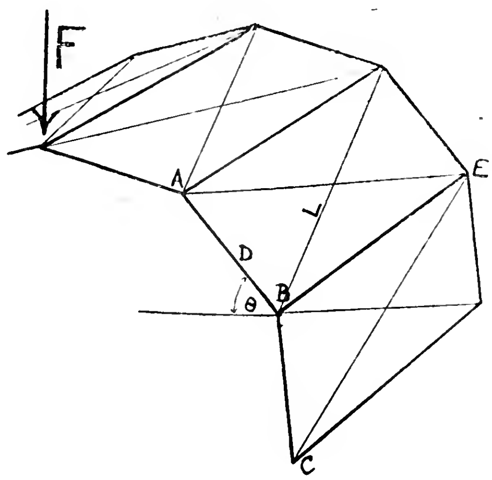
Results such as these are extremely useful and indicate to a designer what probably would be the ideal form for an airship. It must be clearly understood, however, that considerations other than form must enter into the problem of design, and if an ideal form requires an increased hull weight, due perhaps to the increased strength required in transverse frames, it is conceivable that a ship might be ideal in form and yet far from ideal as regards the percentage of the gross lift that is available for useful load. This is pointed out merely to indicate that a designer has to compromise and hold a balance between various conflicting ideals.

It is important to note that the condition for similar flows is independent of the type of fluid, and the total resistance of an airship might be predicted from experiments on a model totally immersed in water or other fluid. As it is impracticable in a wind tunnel to attain a value of vl, anything comparable to the vl of a full-sized airship, it is possible that for quantitative estimation of total resistance of an airship regular series of experiments will at some future time be carried out in a fluid where ρ/U is large compared with that of air, and if sufficiently large it will be practicable to reach values of $\rho vl/U$ more nearly approaching those for the full-sized airship than is at present feasible with a model whose resistances are measured in a wind tunnel.

In order to check the degree of reliability of all model experiments, whether in air or in a liquid, it appears essential to carry out towing experiments on a full-sized airship form. This would be following the precedent of William Froude, whose towing experiments in the "Greyhound" have firmly established the system whereby naval architects may predict from models the resistances of full-sized ships.

APPENDIX I.

DISTRIBUTION OF SHEARING FORCE ACROSS A SECTION.



The figure represents a portion of the outer surface of a ship with a simple system of diagonal wires.

Let θ = inclination of panel AE to the horizontal.
F = vertical shear taken from the curve of shearing force.
x = small vertical movement of frame ABC due to F.
L = length of diagonal wires.
D = length of transverse girder AB.

Then

$$L^2 = (D \sin \theta)^2 + K^2$$

where K is a constant for the panel. K is actually the horizontal projection of L.

$$2LdL = 2D \sin \theta \ . \ d\,(D \sin \theta)$$
$$= 2xD \sin \theta \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

If A be the sectional area of the wire and T its tension

$$T/A = EdL/L \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

From (1) and (2)

$$TL^2/EA = xD \sin \theta \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

D, L, E and x are constants for the section.

Therefore equation (3) becomes

$$T/A = c \sin \theta \text{ where " } c \text{ " is a constant} \quad . \quad . \quad . \quad (4)$$

The shearing force F is the summation over the section of the vertical components of T.

Therefore

$$F = \Sigma Ac \sin \theta \, (D/L) \sin \theta \quad . \quad . \quad . \quad . \quad . \quad (5)$$

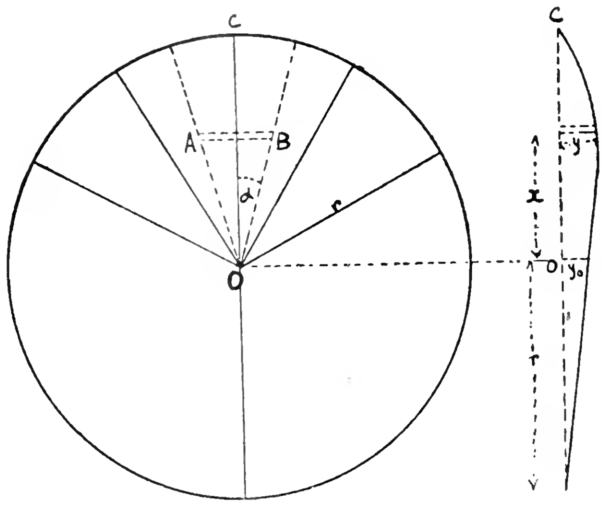
From (4) and (5) we have, eliminating " c "

$$T = FLA \sin \theta / D\Sigma\, (A \sin^2 \theta)$$

APPENDIX II.

TENSIONS IN RADIAL WIRES DUE TO GASBAG END PRESSURES.

Consider a pure radial system and assume that each wire supports the whole of the end pressure on a sector of angle 2α.



Gasbag pressure varies as $(r + x)$ if bag is just full.

Pressure on AB is given by equation

$$p = k\,(r + x)\,2x \tan \alpha dx$$

Equation of equilibrium of wire OC is

$$-T\,(d^2y/dx^2) = 2k\,(r + x)\,x \tan \alpha \quad . \quad . \quad . \quad . \qquad (1)$$

where T is the tension in the wire.

$$\therefore\ -T\,(dy/dx) = 2k \tan \alpha\,(rx^2/2 + x^3/3) + C \quad . \quad . \qquad (2)$$

$$-Ty = 2k \tan \alpha\,(rx^3/6 + x^4/12) + Cx + C' \quad . \quad . \quad . \qquad (3)$$

$$\text{When } x = 0 \ \ y = y_0 \ \therefore\ C' = -Ty_0.$$

Equation (3) becomes

$$T\,(y_0 - y) = 2k \tan \alpha\,(rx^3/6 + x^4/12) + Cx \quad . \quad . \quad . \qquad (4)$$

$$\text{when } x = r \ \ y = 0$$

$$\therefore\ Ty_0 = 2k \tan \alpha\,(r^4/4) + Cr$$

$$C = Ty_0/r - \tfrac{1}{2}kr^3 \tan \alpha$$

Equation (2) becomes

$$-T\,(dy/dx) = 2k \tan \alpha\,(rx^2/2 + x^3/3) + Ty_0/r - \tfrac{1}{2}kr^3 \tan \alpha$$

whence

$$\begin{aligned}(dy/dx)^2 = {} & [(4k^2 \tan^2 \alpha)/T^2]\,[r^2x^4/4 + rx^5/3 + x^6/9] + y_0{}^2/r^2 \\ & + k^2r^6 \tan^2 \alpha/4T^2 + [4ky_0 \tan \alpha/Tr]\,[rx^2/2 + x^3/3] \\ & - [2k^2r^3 \tan^2 \alpha/T^2]\,[rx^2/2 + x^3/3] - ky_0r^2 \tan \alpha/T\end{aligned}$$

Now the stretch of the wire OC, assuming no vertical movement of O is given by

$$1/2 \int_0^r (dy/dx)^2\, dx$$

$$= \tfrac{1}{2} \left[\begin{array}{l} [4k^2 \tan^2 \alpha/T^2]\,(r^2x^5/20 + rx^6/18 + x^7/63) + y_0{}^2x/r^2 \\ + [k^2r^6x \tan^2 \alpha/4T^2] + [4ky_0 \tan \alpha/Tr]\,(rx^3/6 + x^4/12) \\ - [2k^2r^3 \tan^2 \alpha/T^2]\,(rx^3/6 + x^4/12) - [ky_0r^2x \tan \alpha/T] \end{array} \right]_0^r$$

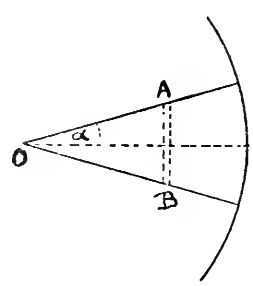
which simplifies down to

$$\text{Stretch of wire} = (33/280)\,(k^2 \tan^2 \alpha r^7/T^2) + (y_0{}^2/2r)$$

$\therefore$ If A = area of section of wire
E = modulus of elasticity

$$Tr/EA = (33/280)\,(k^2 \tan^2 \alpha r^7/T^2) + y_0{}^2/2r \quad . \quad . \quad . \quad (5)$$

For the *horizontal wire* we have



$$\text{Pressure on } AB = kr2x \tan \alpha dx$$

Proceeding as for vertical wire we get

$$-T\,(dy/dx) = 2kr \tan \alpha\,(x^2/2) + Ty_0/r - (kr^3/3) \tan \alpha \quad . \quad . \quad (6)$$

$$\text{Stretch} = 1/2 \int_0^r (dy/dx)^2\, dx$$

$$= y_0{}^2/2r + (2/45)\,(k^2r^7 \tan^2 \alpha/T^2) \quad . \quad . \quad . \quad . \quad (7)$$

For the *lower vertical wire*

$$\text{Stretch} = y_0{}^2/2r + (17/2520)\,(kr^7 \tan^2 \alpha/T^2)$$

So we have the three equations

Top wire ... $Tr/EA = y_0{}^2/2r + (33/280)\,(k^2r^7 \tan^2 \alpha/T^2)$
Horizontal wire $Tr/EA = y_0{}^2/2r + (2/45)\,(k^2r^7 \tan^2 \alpha/T^2)$
Bottom wire ... $Tr/EA = y_0{}^2/2r + (17/2520)\,(k^2r^7 \tan^2 \alpha/T^2)$

These equations assume no vertical movement of O, the centre ring. Actually O would move slightly upward equalising the tensions in the top and bottom wire. Now the mean of these two tensions is very approximately that given by the equation for the horizontal wire.

Therefore it is assumed that the movement of O is such as to make all the wire tensions equal to that given by the formula

$$Tr/EA = y_0{}^2/2r + (2/45)\,(k^2r^7 \tan^2 \alpha/T^2)$$

The introduction of an axial wire might be assumed to make $y_0 = 0$ and our equation becomes

$$Tr/EA = (2/45)\,(k^2r^7 \tan^2 \alpha/T^2)$$

$$\text{or } T = C\sqrt[3]{A} \tan^{2/3}\alpha \;.\; r^2$$

APPENDIX III.

RESISTANCES OF SIMILAR BODIES MOVING THROUGH FLUIDS.

Let ρ = density of fluid $\left[\dfrac{M}{L^3}\right]$

U = coefficient of viscosity $\left[\dfrac{M}{LT}\right]$

V = velocity $\left[\dfrac{T}{L}\right]$

R = resistance $\left[\dfrac{ML}{T^2}\right]$

L = length or linear dimension indicating the scale of the body.

Viscosity per unit density is known as "*kinematic viscosity*" and resistance per unit density as "*kinematic resistance*," so let

$$v = U/\rho = \text{kinematic viscosity} \left[\frac{L^2}{T}\right]$$

$$F = R/\rho = \text{kinematic resistance} \left[\frac{L^4}{T^2}\right]$$

The kinematic resistance to motion through a fluid, of a totally immersed body, depends on v, V and L.

So we may write generally

$$F = cv^p V^q L^r \quad \ldots \ldots \quad (1)$$

Writing this equation dimensionally we have

$$\frac{L^4}{T^2} = c\,\frac{L^{2p}}{T^p}\,\frac{L^q}{T^q}\,L^r$$

whence

$$4 = 2p + q + r$$
$$2 = p + q$$
$$\therefore\ q = r \text{ and } p + r = 2$$

so our equation (1) becomes

$$F = cv^p V^r L^r \quad \ldots \ldots \quad (2)$$

where $p + r = 2$.

CONDITION FOR SIMILAR FLOWS AROUND GEOMETRICALLY SIMILAR BODIES MOVING THROUGH FLUIDS.

Using notation as above.
Type of flow depends on v L and V.
Write

$$L = cv^p V^q \quad \ldots \ldots \quad (3)$$

Dimensionally

$$L = c\,\frac{L^{2p}}{T^p}\,\frac{L^q}{T^q}$$

$$\therefore\ 2p + q = 1$$
$$p + q = 0$$
$$\therefore\ p = 1 \quad q = -1$$

So equation (3) becomes

$$L = cv/V$$

$$\text{or } \rho VL/U = \text{constant.}$$

In the same fluid we might take ρ/U as being constant, then our condition for similar flows around similar bodies becomes

$$VL = \text{constant.}$$

Hence, *for a ship and model moving through the same fluid, totally immersed, the corresponding speeds vary inversely as the linear dimensions.*

Equation (2) gives

$$F = cv^pV^rL^r \text{ where } p + r = 2$$

and for similar flows VL/v = constant (say) K, so we have

$$F = c\,\frac{V^pL^p}{K^p}\,V^rL^r$$

$$= \text{constant} \times (VL)^{p+r}$$

$$= \text{constant} \times V^2L^2 \text{ since } p + r = 2$$

and since $F = R/\rho$

$$R = c\rho V^2L^2$$

where $\rho VL/U$ is constant.

In the same fluid v is constant and equation (2) might then be written

$$F = \text{constant } V^rL^r$$

and for similarity of flow in the same fluid we have VL = constant.

$\therefore$ Under these conditions F = constant.

R = constant.

That is, *in the same fluid and at corresponding speeds the resistances of a ship and its model are the same.*

REVIEW.

The Mechanical Principles of the Aeroplane. S. Brodetsky. (J. and A. Churchill.)

This book, intended for the use of University students, gives an account of the mathematical problems of the flight of an aeroplane and is divided into three main sections, dealing respectively with motion in air, dynamics of air and aeroplane motion. The quality of the book is curiously uneven and the author is happiest when dealing with purely mathematical questions. The discussion of periodic solutions of the motion of a body and of the various equilibrium conditions is very valuable, and the introduction to the theory of irrotational motion of a fluid is excellent. On the other hand, the lengthy discussion of discontinuous fluid motion is of very doubtful value in the science of aeronautics. In all practical problems the surfaces of discontinuity break up into a series of vortices, and this chapter of the book could be replaced with advantage by one dealing with circulation round a body and with simple vortex motion.

The chapters dealing with the aeroplane, as distinct from dynamics or hydrodynamics, appear to indicate insufficient experience of the real problems of aeronautics. Various statements are distinctly misleading, if not inaccurate, as for example when it is stated that an aeroplane is made to climb by increasing the speed and decreasing the thrust (p. 64). Also on p. 68 we read: "Since aerofoils have the property that for a certain angle of attack the L/D ratio begins to sink rapidly, the danger of flying too slowly, or of trying to climb too steeply, is obvious. This is called stalling the machine!"

As regards Section III. of the book, it is indeed true that the aeroplane has been idealised out of all recognition. A discussion of stability which ignores the movement of the centre of pressure and the downwash of the main planes may be interesting mathematically, but is worthless in aeronautics and must be misleading to the student, while the treatment of the problem of the airscrew suffers from similar defects and is very sketchy. "The Mechanical Principles of the Aeroplane" would have been a good book six years ago.

A final word must be said about the new system of notation introduced by the author. The particular merits of the scheme are by no means obvious. In the standard system it is easy to remember that Xu denotes the differential of X with respect to u, but there is no single connection between a_x or f_2 and the corresponding forces and velocities.

H. G.

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Edited for the Council by J. LAURENCE PRITCHARD, Fellow.

All communications should be addressed to the Editor.

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Notices of the Royal Aëronautical Society.

Examinations.

On another page will be found the Syllabus of the Society's Examination for Associate Fellowship. This syllabus together with the rules and regulations for the admission of Fellows and Associate Fellows will shortly be available as a pamphlet. Intending candidates are reminded that the first examination will be held in April, 1922.

" Rigid Airships."

It is regretted that through an oversight the fact that Mr. J. L. Bartlett's two lectures on "Rigid Airships," printed in the July number of the Journal, were delivered before the Scottish Branch was not stated.

Scottish Branch.

The following have been elected to the Scottish Branch :—

Member.—Capt. A. Douglas S. Barr.

Associate Members.—A. P. Donald, Capt. A. McR. Moffatt.

Lecture Programme.

The programme of lectures for 1921-1922, being the Fifty-Seventh Session since the inauguration of the Society, so far as at present arranged is as follows :—

Nov	3.	" Manœuvres of Getting Off and Landing." R. M. Hill.
,,	17.	" Requirements and Difficulties of Air Transport." Col. F. Searle.
Dec.	1.	" Design of a Commercial Aeroplane." Capt. G. de Havilland.
,,	15.	" Development of the Fighting Aeroplane." Capt. F. M. Green.
1922.		
Jan.	5.	" Specialised Aircraft." Wing Comdr. W. D. Beatty.
,,	12.	Juvenile Lecture. (Lecturer to be announced later.)
,,	19.	" Aeroplane Installation." Brig.-Gen. R. K. Bagnall Wild.

Feb. 2. "Radiological Research and the Examination of Materials." Dr. V. E. Pullin.
,, 16. "Methods of Instruction in Aeroplane Flying." Squadron Leader C. F. A. Portal.
Mar. 2. "Testing Aircraft to Destruction." W. D. Douglas.
,, 30. "Airships." (Lecturer to be announced later.)
Apl. 6. (Subject to be announced later.) Mons. Breguet.

The lectures will be held in the Theatre of the Royal Society of Arts, Adelphi, at 5.30 p.m.

W. Lockwood Marsh,
Secretary.

ASSOCIATE FELLOWSHIP.

SYLLABUS OF EXAMINATIONS

(In accordance with Clause VI. of the Regulations).

PART I.

(*General Educational Qualification.*)

ENGLISH (One Paper).—A general paper comprising questions in Geography, History and Literature,

or

French, German, Italian, Spanish: Each paper will contain passages to be translated into English from books not previously prescribed, together with questions in grammar and a passage to be translated from English into the language selected by the candidate.

ELEMENTARY MATHEMATICS (One Paper).

Arithmetic.—The principles and processes of arithmetic applied to whole numbers and vulgar and decimal fractions. The metric system. Approximations to a specified degree of accuracy. Contracted methods of multiplication and division of decimals. Ratio and proportion. Percentage. Averages. Practical applications of arithmetic. *Algebra.*—Symbolical expressions. Equations of the first or second degree (and problems leading thereto). Square root. Graphs of simple rational integral algebraic functions. Arithmetic and harmonic progression. Geometric progression. Theory of indices. Logarithms. Theory and use of the slide rule. Binomial theorem for a positive integral index. *Geometry.*—The subjects covered by Euclid I.-IV. with simple deductions, including easy loci and the areas of triangles and parallelograms of which the bases and altitudes are given commensurable lengths. (Euclid proofs will not be insisted upon.) *Trigonometry.*—Up to and including the solution of triangles, together with the practical solutions of triangles and applications, and numerical examples involving the use of logarithmic and other tables.

PART II.

(*Technical Qualification.*)

One Paper in any two of the following subjects.

(*a*) STRENGTH AND ELASTICITY OF MATERIALS AND THEORY OF STRUCTURES.

Strength and Elasticity of Materials.—Physical properties and elastic constants of metals and timber. Relation of stress and elastic strain. Limit of elasticity. Yield point. Young's modulus. Shear modulus. Poisson's ratio. Compression, shear and torsion. Thin cylindrical shells. Strength and deflection in simple cases of bending. Beams of uniform resistance. Suddenly-applied loads.

Ultimate strength with different modes of loading. Plasticity. Working stress. Phenomena in an ordinary tensile test. Stress-strain diagram. Elonga-

tion and contraction of area. Effects of hardening, tempering and annealing. Fatigue of metals.

Forms and arrangements of testing machines for tension, compression, torsion, bending and hardness. Notched-bar testing machine. Instruments for measuring extension, compression and twist. Forms of test pieces and arrangements for holding them. Influence of form on strength and elongation. Methods of ordinary commercial testing. Percentage of elongation and contraction of area. Test conditions in specifications for metallic and non-metallic aircraft materials.

Theory of Structures.—Graphic and analytic methods for the calculation of bending moments, shearing forces and deflection, and of the stresses in individual members of framework structures, loaded at the joints. Principle of least work. Redundant frames. Stresses suddenly applied and effects of impact. Buckling of struts. Combined stresses. Theorem of three moments with its aeronautical generalisation. Riveted and pin-joint girders.

(*b*) AERODYNAMICS.

Physical properties of the atmosphere. Viscosity. Flow of air past immersed bodies. Streamlines and eddies. Distribution of surface pressure in important cases and calculation of resultant force therefrom. Bernoulli's theorem.

Simple laws of resistance. Fairing of form. Skin friction. Pitot tube. Theory of physical dimensions applied to similar motions.

Applications of the principle of dynamical similarity in aeronautics.

Arrangement and justification of model experiment.

Apparatus and methods for accurate work in the aeronautical laboratory. Mutual interference of air-flow by adjacent bodies. Reduction of results. Forces and moments on bodies inclined to the relative wind. Centre of pressure. Axes of reference. Nomenclature.

Properties of aerofoils. Biplanes and triplanes. Scale effects. Downwash.

Blade element theory of airscrews. Froude's theory and translational inflow. Lay-out and design.

Types and construction of aeroplanes and airships. Controls. Equilibrium.

Steady flight in straight line, horizontal circle, helix. Manœuvres. Load factor.

Comparison of experimental data and application to aircraft design. Computation of total resistance. Power curves and analysis of performance.

Elements of stability. Nature and definition. Functions of stabilising surfaces. Phugoid oscillations. Records of full-scale experimental work.

Full-scale data.

(*c*) HEAT ENGINES.

Internal Combustion Engines.—Combustion and explosion of inflammable gases and vapours in air. Pressures and temperatures of explosion at different initial pressures. Variable specific heat. Effect of combustion chamber form and materials on performance. Effect of compression. Effect of altitude.

Four-stroke engines. Two-stroke engines. Arrangements of inlet and exhaust valves. Valve timing. Electrical ignition. Piston design. Diesel engines. Ignition by compression temperatures. Petrol engines. Carburettors.

Stresses due to inertia of moving parts. Balancing of engines. Valve gear diagrams. Speed reduction gears. Air and water cooling. Fuels and lubricants. Lubrication. Petrol systems.

Theory of Heat Engines.—Thermodynamic laws. Internal and external work. Graphical representation of changes in the condition of a fluid. Theory of heat engines working with a perfect gas. Air- and gas-engine cycles. Reversibility. Conditions necessary for maximum possible efficiency in any cycle. The Carnot cycles. Actual heat engine cycles and their thermodynamic losses. Testing of heat engines and the apparatus employed.

(*d*) METEOROLOGY AND NAVIGATION.

Meteorology.—Nature of atmosphere. Circulation. Dynamical heating and cooling. Temperature distribution. Measurement of altitude. Stratosphere and troposphere. Measurement of wind velocity at altitude. Gradient wind. Turbulence. Forecasting weather. Occurrence of fog. Atmospheric electricity. Precipitation and frost. Solar radiation.

Navigation.—Methods of aircraft pilotage. Measurement of ground speed, track and drift. Air speed and turn indicators. Magnetic compass theory and compass correction. Methods of measuring velocity of wind whilst in flight. Navy pattern and bubble sextants. Artificial horizons. Reduction of astronomical observations by position-line slide rules or by tables. Two-star tables. Plotting position lines for astronomical and for direction-finding wireless telegraphy observations. Use of gyrostats. Effect of periodic yaw, pitch and roll on navigational instruments.

(*e*) MATHEMATICS.

Hydrostatics.—Centre of pressure. Equilibrium of floating bodies. Metacentre. Steady rotating fluids.

Dynamics.—Rectilinear and circular motion. Centre of instantaneous rotation. Linear and angular momentum. Work and energy. Centre of mass and moment of inertia. Motion about a fixed axis. Dimensions of physical quantities. Impact and shock. Equations of motion of a rigid body with simple applications. Simple theory of the gyroscope. Elementary graphical statics.

Algebra.—Algebraic equations. Solution by Dunois theorem. Graaffe method. Summation of series in simple cases. Graphs and equations. Solutions by graphical methods. Solid geometry up to dimension cosines.

Differential and Integral Calculus.—Average velocity. Velocity at a point. Acceleration. Slope of a curve. Limits. Simple cases of maxima and minima. Differentiation of standard functions. Indefinite integration. Integration by change of variable. Definite integration. Areas and surfaces. Volumes. Mass centres. Moments of inertia.

Integration by parts and partial fractions. Maclaurin's and Taylor's theorems. Expansions for $\sin x$, $\cos x$, etc. Hyperbolic functions and their properties. Linear differential equations with constant coefficients, and their applications. Periodic motion. Forced vibration. Resonance. Torsional oscillations in shafting. Whirling of shafts.

(*f*) CHEMISTRY AND METALLURGY.

Chemistry.

Fabrics.—Linen, cotton and silk, characteristics and use. Properties required in material intended to be used for aeroplane coverings, hangars, parachutes, airships, etc. Methods of tests. Proofing of airship fabric, hangar canvas. Fireproofing of parachutes. Causes of deterioration of fabric and methods of protection. Cordage types and requirements. *Dope and Protective Coverings.*—General composition of acetyl and nitro-cellulose dopes. Functions. Methods of

prevention of deterioration. Chemical and physical tests. Composition and characteristics of protective coverings. *Fuels* for internal combustion engines from light spirit to heavy oil. Alcohol. Synthetic fuels. Chemical and physical tests. *Adhesives.* Casein and gelatine glue. Characteristics and uses as applied to aircraft. Chemical and physical tests. *Oils.* Characteristics of oils for use in aircraft engines, instruments, machine guns, etc. Causes of failure. Chemical and physical tests. *Rubber.*—Petrol proof tubing. Shock absorbers. Tyres. Airship fabric. Chemical and physical tests. *Anti-fouling liquids.*—Essential properties of liquids for use in compasses, radiators, buffers, etc. *Hydrogen for airships.*—Manufacture, properties and tests. *Paints and varnishes.*—Composition and properties required in paints and varnishes used for protection of metal and woodwork.

Metallurgy.

Methods of casting metals and alloys. Effects of casting temperature on structure and properties. Effects of types of moulds. Defects in castings.

Effect of forging, drop forging and rolling on structure and properties of cast metals.

Effect of cold working upon structure and properties of metals.

Steel.—Manufacturing processes and apparatus used. Nature and method of carrying out heat treatment including casehardening. Effect of heat treatment upon mechanical properties of steel. Relationship of chemical composition of steel to mechanical properties. Typical chemical composition of plain carbon and alloy steel. Mechanical properties at high temperatures. Properties of cold worked steel. Effects of impurities on the properties of steel. Corrosion and scaling and prevention of corrosion.

Non-Ferrous Metals.—Chemical composition of alloys of copper, zinc and aluminium. Mechanical properties of above alloys, etc., in the cast and (when possible) in the wrought condition. Effect of cold working on the mechanical properties of the above alloys, etc. Mechanical properties at high temperatures.

[NOTE.—Sufficient questions will be set in chemistry to allow of a candidate passing on this paper without taking any questions in Metallurgy, and vice versa.]

PROCEEDINGS.

ELEVENTH MEETING, 56th SESSION.

The Eleventh and last Ordinary Meeting of the Fifty-Sixth Session took place in the Hall of the Royal Society of Arts, London, on Thursday, March 17th, 1921, Major A. R. Low presiding.

The CHAIRMAN said he needed no words to introduce the Lecturer to that meeting. He would call on him at once to read his Paper.

Captain DAVID NICOLSON, A.M.I.N.A., M.I.E.S., A.F.R.Aë.S., then delivered the following Lecture :—

FLYING BOAT CONSTRUCTION.

The design and construction of light hulls and floats suitable for flying boats and seaplanes is a very highly specialised branch of shipbuilding. This being the case, all matters pertaining to same should be in the hands of naval architects. At a recent lecture before this Society, Commander Hunsaker, of the United States Navy, stated that British aircraft designers followed the naval architect's methods more than in any other country; he thought this was natural as he gave us the credit of being the first maritime power of the world. This may be perfectly true with regard to airships, but I cannot endorse his opinion that the majority of flying boats built in this country show the impress of the trained hand of a naval architect. I do not imply that the American boats are superior to ours, as for instance, a large American boat with twin engines built in the United States, which we used for the North Sea patrol, was by no means typical of good boat-building; there were no less than four consecutive planks butted—not even scarfed—on the same timber, which had a siding of $\frac{5}{8}$in., the line of butts being in line with the step where the boat was naturally weakest.

The Curtis boat, as originally built, was wall-sided, *i.e.*, without projecting side fins to the front step and planing bottom, but as it experienced difficulty in getting off the water, the breadth of the step was increased by adding fins, thereby improving the planing efficiency, although the fins in service were very liable to damage.

American built boats were later on imported in considerable numbers, but although the workmanship and materials were much improved, they were still weak owing to lack of continuity in the structural design, and frequent damages were reported, until at length the whole bottom had to be stiffened by timbers and stringers.

Boats of the "F" type which followed were a great improvement on the original type, but as in the previous boats, the bottoms gave trouble owing to the faulty keel and bottom construction.

For the past two years many builders have been debating about the construction of flying boats. On the one side it has been contended that flying boats should be built as light as possible, and that there should be no restriction whatever placed upon the designer in the matter of the construction. In support of this it was said that the designer must of necessity build his hull strong enough, otherwise she would lose her shape. It would also be very unwise to tie a clever designer's hand with a more or less hard and fast table of scantlings.

The arguments on the other hand were of a purely practical nature. It was maintained that the keenness of competition was such that, if lightness of construction were unlimited, most flying boats would be weak, and probably unseaworthy. The same vexed question of scantlings was much discussed a few years ago by yacht-builders as to whether racing yachts should be classified by Lloyds and built under their rules. Arguments on similar lines to the above were put forward by the two schools of thought, and after the International Conference of 1906, the yachtsmen of Europe decided to abandon all theoretical contentions, and they passed a rule that every yacht racing under the rules of the International Yacht Racing Union must be classed either by Lloyds Register of Shipping or other corporation. And now, in my opinion, similar rules should be drawn up for the construction of flying boat hulls. In coming to this conclusion, it must not be supposed that designers would place themselves unreservedly in the hands of the classification committee, as in the case of yacht-building hard and fast jurisdiction or monopoly of surveying the building can be guarded against. Every racing yacht must be built according to the rules and scantling tables, but the choice of material is left to the owner or builders, provided it will pass the inspectors. Again, provided the yacht obtains the class "R," the owner is not obliged to obtain the class for her for any special term of years. Thus one yacht may be classed "10 R," another "12 R," and another "14 years R," and all would be equally eligible under the Y.R.A. rules. Regulations similar to the foregoing could also apply to boats built for civil aviation but with a much shorter period.

In some cases floats were built and passed for civil aviation, and when similar floats were required for the services they had all to be strengthened, many extra fastenings put in the butt joints, heavy butt straps fitted, and special diagonal stiffeners put on the bulkheads. If the floats required all the extra strengthening for the services, surely for civil work, when probably more lives were depending on these floats, they should have been made to the same specification; or if they had been passed, a certificate for only a few months should have been given. Again, the gusset pieces of three-ply were only glued and tacked to the frames, and when the services required the floats they had all to be through fastened and the edges protected, and if this had been carried out on the civil aircraft, a class for, say, two years, could then have been granted. Extra periods of classification should be granted according to the fastenings and materials used. In granting certificates for airworthiness in civil aircraft, the technical department might include seaworthiness for all flying boats and also classify them yacht fashion and give a period when the boat should again be surveyed.

If a boat is built to rules, the class is determined by the scantlings and equipment, and is adopted for the purpose of insurance in some cases. In building to a class, the scantlings of all the structural parts are fixed by the table of rules, thus ensuring uniformity of weight of structure. If we consider the case of the "F" type of boat, it will be seen that there is no uniformity of weight of structure, the nose is much too heavy, the stringers too closely spaced, while the timbers and bottom are much under strength. If we are to carry passengers in flying boats, then their safety if they have to alight at sea must be considered.

Since longitudinal damage is most destructive as regards loss of buoyancy, the criterion of risk should be measured longitudinally and under water. Therefore some regulations should be drawn up by means of a criterion of risk which involves a longitudinal under-water tear extending for a constant percentage of the length of the boat.

All interested in the design and construction are seriously concerned with the present unsatisfactory position of the watertight sub-divisions and bulkheads. At a paper read by the late Major Linton-Hope before this Society, much discussion

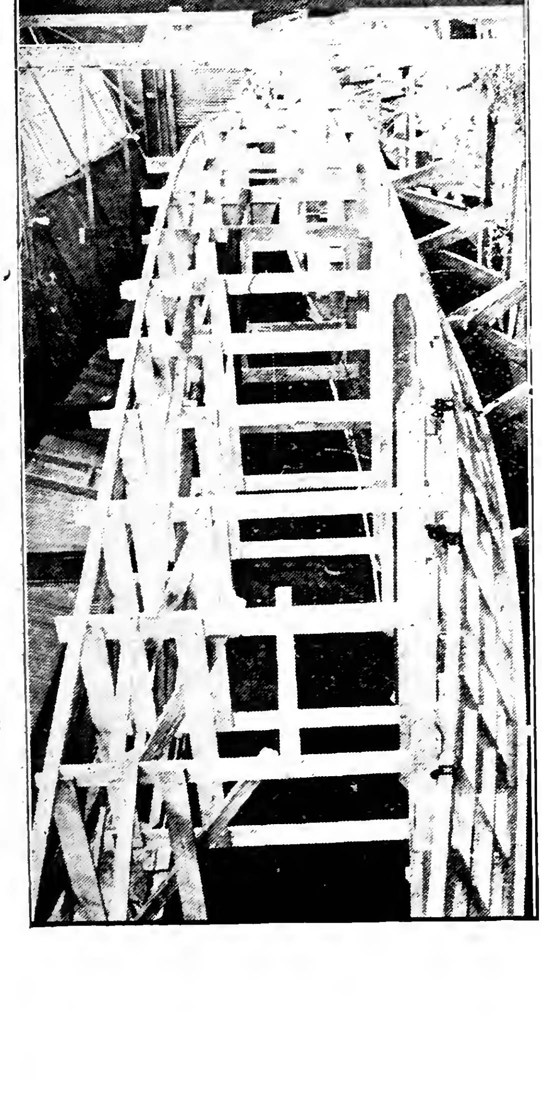


Photo No. 1.—F boat, showing wrong method of holding moulds together.

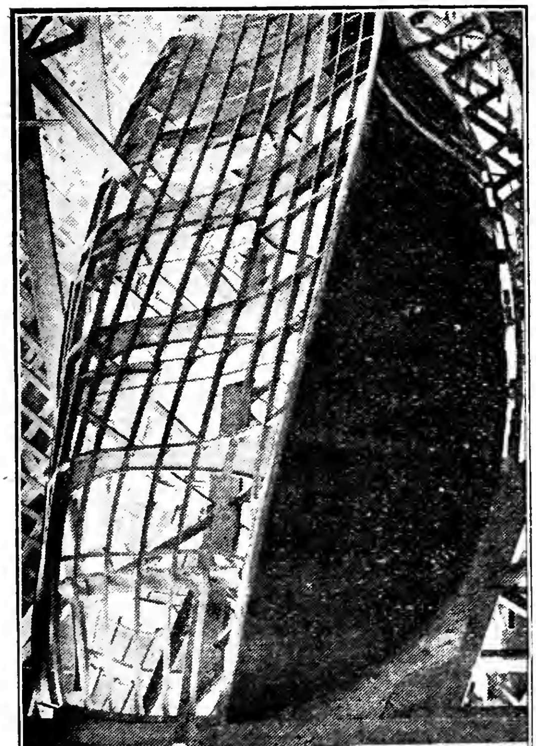


Photo No. 2.—N4, showing web frames and longitudinals.

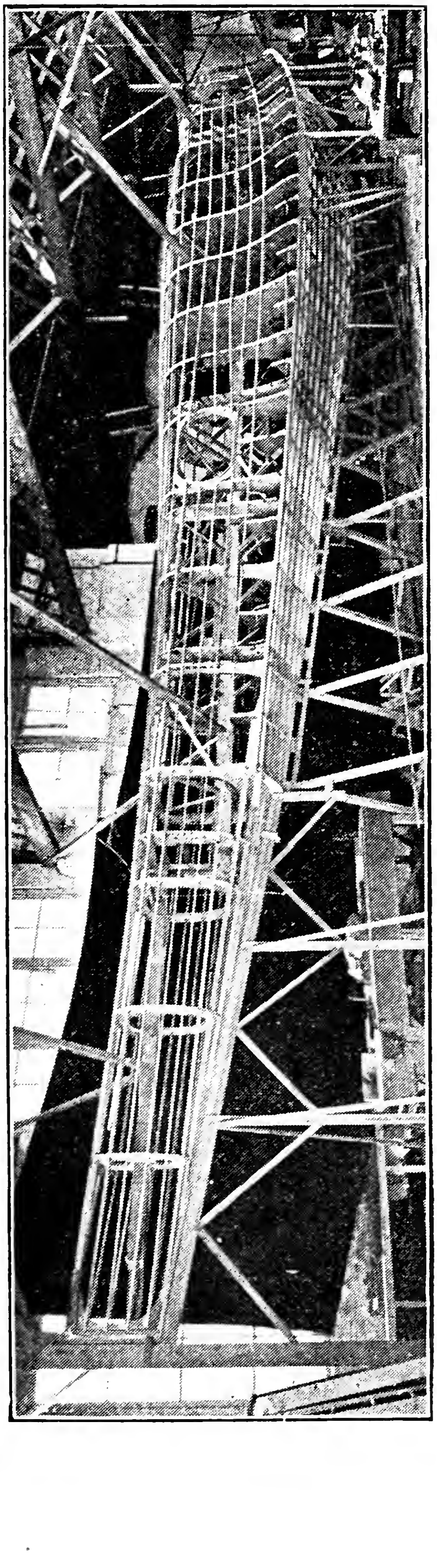


Photo No. 3.—N4 Atalanta. Skeleton view showing longitudinal system.

took place on this very important subject, and yet up to the present no action has been taken to remedy same. The principal difficulty is to fit a bulkhead that will stand the inrush of water, and yet be resilient to pant if the hull is resilient. In my opinion this can be got over by adopting lap or expansion joints instead of edge to edge or tub joints as is now practised.

Bulkheads are useful in three ways—as W.T. divisions, as fire screens, and as structural diaphragms. In the first capacity they may confer immunity from sinking, for should water enter the boat as a result of damage to the skin, it may be confined to the one space; in the second they may, should a fire occur, confine the conflagration to the one space, facilitate its extinction and limit the damage. In the foregoing two capabilities, their usefulness is only potential, but in the third, as structural diaphragms, they are at all times beneficial, for by uniting the bottom sides and deck, they are most efficient in checking any tendency to alteration in the form of the transverse sections, due to racking or panting stresses. Although bulkheads give immunity from foundering, their capabilities in this respect are dependent on many circumstances. The sub-division of the hull must be such that if any compartment be flooded, the loss of reserve buoyancy will not cause the boat to sink. Also if the bulkhead be weakly constructed, it might collapse under the water pressure or it may not be thoroughly watertight. Again, the bulkhead must be built above L.W.L., for if not, as the water rose in the bilged compartment and the boat subsided, it would flow over and fill the adjacent holds. In the past flying boats these qualities do not seem to have been taken note of, and as far as I can see, the bulkheads only acted as structural diaphragms, and very poor specimens at that. Another point worthy of note would be the making of the centre keelson watertight, thus forming a sub-division right fore and aft.

I have not mentioned the alteration in trim due to the flooding of any compartment, as with the present small flying boats, this does not affect us very seriously, but when larger boats are built, this will have to be noted as it will regulate the position of bulkheads or the size of the various holds.

The subject of bulkheads covers such a large field, especially when fire-resisting material and construction is desirable, that it is not possible here to deal with it to any great extent. The same subject was for many years attracting the attention of shipbuilders, with the result that a special committee was appointed to draw up rules and methods of construction to secure the benefit of safety. It is my opinion that if such a committee was considered necessary for ships, a similar committee of naval architects should be appointed to deal with flying boat bulkheads.

Before touching upon the detail of construction, I think a few words on the "laying off" would not be out of place here. To illustrate the importance of the loft work, I should like to point out that it was owing to the bad laying off that many flying boats at the sea stations required individual trolleys for themselves which had to be specially shaped at the station to take one particular boat. If all these boats had been laid off by a naval architect who appreciates the fineness of the scrieve board lines, then the correct offsets supplied to each builder who would not have required to do any fairing in or out, and if the moulds had been properly held by ribands, all the boats would have been very close in shape. I am aware that many engineers and aircraft builders do not realise to what fine limits naval architects have to work when scrieving out the lines. I have often heard it stated that anything from $\frac{1}{4}$in. to $\frac{1}{2}$in. in or out did not matter, hence the reason for so many unfair boats. If a yacht-builder worked to these lines, I am afraid many of his racing yachts would be outclassed if she drew $\frac{1}{4}$in. more than her designed draft; and soon the builder would have to construct flying boats for the agents who consider that such fine lines are not necessary.

Aircraft manufacturers who have not had any experience in power boat building will find it essential to lay a mould loft floor if they intend building flying boat hulls, and when the floor is properly laid and painted, fair lines will be much more easily scrieved. In the first place, the sheer plan must be delineated on the floor, then the half breadth, and finally the body plan. When these have been scrieved and the thickness of plank removed, then the moulds for frames can be lifted direct, also the various moulds showing the shape of different parts of the hull, battens and templates giving precise information as to the sizes and disposition of the structural parts can then be lifted. These lines are very useful as they often dispense with the necessity of fitting a mock-up in the shops. When the moulds are made, the stocks have to be set to take same, and here many of the builders of flying boats placed these about one foot above the floor to find that when the boat was ready for rivetting they had to lift the whole hull and raise the stocks to a convenient height to allow the men to work under. The moulds now set in place on the stocks have to be kept in position by ribands, each riband running the whole length of the boat; here again many builders erred by fastening each pair of moulds together by small battens, as will be seen in

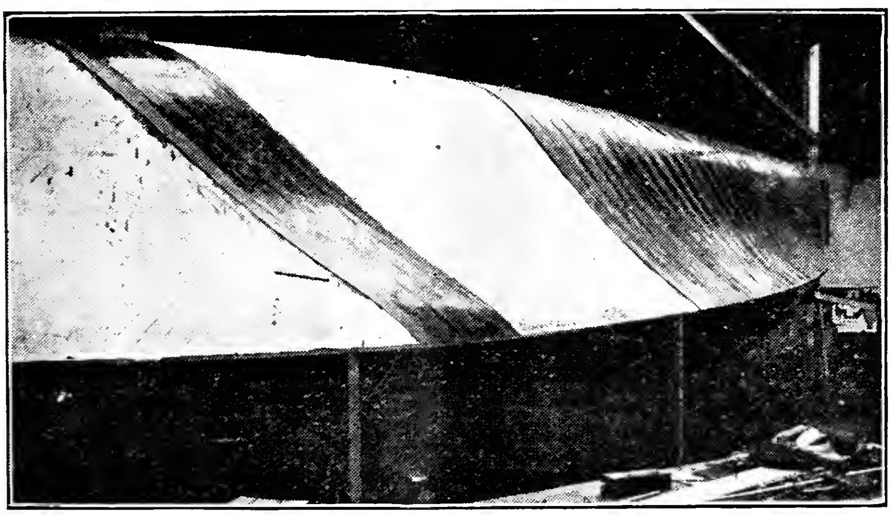


Photo No. 4.—N4 Atalanta. View from amidships, looking forward.

photograph No. 1, and then they wondered why the boat was not fair when she was planked up. A good example of this was seen in the F.5 boats, where many metal fittings were made to a jig by one firm to obtain good production, but this object was defeated as many of the fittings did not coincide with their structural part, therefore the various builders had then to make their own fittings to suit their particular lines.

The principal feature in many hulls is the skin; all the other structural parts are more or less subsidiary, their function being to support and stiffen it. The skin is stiffened by framework disposed transversely and longitudinally, and further the sides are united by beams to support same against collapse. The same total strengthening can be effected by heavy frames spaced at wide intervals or by numerous small frames spaced very closely, but these systems cannot, for practical reasons, be exceeded, as in the former if the frames were widely spaced and proportionately heavy, they might preserve the form of the hull as a whole, but they would not give sufficient local stiffness to the skin in order that it would not buckle between the frames. If the latter was carried to excess the ultimate result would be equivalent to a mere thickening of the skin. If made sufficiently thick it would be self-supporting, but owing to the excessive thickness it would be too heavy and useless for flying boats.

Before settling the scantlings of a hull, the most efficient disposition of material should be considered in conjunction with the duties the boat has to perform. The cost of construction should also be taken into account, and this is dependent to a certain extent on the quantity of material used and on the method of construction.

If the hull is built of few and heavy parts, it would involve less skilled labour, therefore would be much cheaper, but the hull built of more numerous parts, smaller, but efficiently formed, and disposed of for their more specialised duties, although the initial cost is more, is the better boat, as it will be lighter, and as carrying capabilities are so important, the extra first cost is justified.

In the usual type of hull the transverse frames form continuous ribs round the body, giving to the yielding skin the necessary lateral stiffness, and resist all stresses tending to alter the form of the transverse sections; however, this would give imperfect rigidity, as each one would be independent of the adjoining one, therefore, to give a combined and good resistance, they are united by the keelsons and side stringers. The boat's framework is thus composed of the transverses and longitudinals. The former, disposed in direct contact with the skin, constitute the main skeleton of the hull, the skin and other members being fitted to it as a groundwork. The keelsons and side stringers are fitted in continuous lengths within the transverse which form a supplementary skeleton; these are connected, not merely to the inner surface of the transverse frames, but extend intercostally between them so as to connect to the skin. The lower part of the transverse frames are made specially strong by having the floors connected to same, as the bottom is liable to severe pressures, both widespread and local, through the hull being docked in trol'eys or resting on the keel. For a similar reason the keelsons are made stronger than the side stringers; they also prevent the hull from hogging and sagging. The centre keelson being strongest of all, it might be regarded as the backbone of the hull.

It will be well to notice the difference and relative value of the two qualities, strength and stiffness, or rigidity. If we now consider the efficiency of the frames versus the stringers in stiffening the skin and supporting the sides against deforming forces, the transverse frames are short compared with the stringers as they only go from the keel to the deck, whereas the stringers run the whole length of the boat. It will be seen that the stringers, on account of their great length and consequent elasticity, cannot by themselves give useful resistance to widespread straining forces. Their principal duty is to give local support through their binding effect on the transverse frames, and when fitted intercostally, to stiffen the skin.

I think we might now consider the longitudinal versus transverse system of framing, or it might be stated which of the two kinds of stresses, longitudinal or transverse, should govern the boat's structural design. In the longitudinal system the main fore and afters run all the way of the boat, the web frames being cut out to allow them to pass. The web frames extend round the body of the boat, usually at fairly wide intervals, and are of such depth and massiveness that they form strong and almost inflexible supports to the sides, deck and bottom against all transverse forces. The supporting framework of the deck is arranged like that of the sides, light longitudinals being carried continuously through the deep cross girders. It may be said that in the foregoing system the deep web frames form the main skeleton of the hull, giving it all the necessary transverse strength to maintain unyieldingly its transverse shape. The longitudinals may be regarded as forming stiffening material for the skin and deck, giving these flexible surfaces the necessary rigidity to withstand all bending pressures acting between the supporting transverses (see Photo No. 2).

In comparing the longitudinal with the transverse arrangement of the light subsidiary frames, it will be seen that the heavy side stringers have been dispensed

with; it also possesses the advantage of stiffening the skin against the buckling tendencies brought about by the fore and aft compression stresses which accompany hogging and sagging of the hull. Transverse frames and beams cannot prevent transverse buckling tendencies of the skin between them; to counteract this, they must be placed closely together or the skin increased in thickness. As the compressive stresses above mentioned are most acute at the top of the hull, it is evident that a longitudinal arrangement of beams is even more important than a longitudinal arrangement of side frames.

The longitudinal system is not only advantageous in increasing the longitudinal strength of the hull, but it also means a considerable reduction in weight which, while permitting additional carrying weight, also reduces the first cost.

One of the disadvantages of this system is that the numerous deep projections cause the interior space of hull to be broken.

A good example of the foregoing mentioned longitudinal system is the N.4 Atlanta designed by Mr. Charles E. Nicholson. His method omits the closely spaced transverse frames and beams; the transverse strength is obtained by fitting directly on the skin a series of strong web frames at widely spaced intervals. The longitudinals take the place of ribands, and only require to be secured to the transverses carefully and very little fairing is required (see Photo No. 3).

Photo No. 4 shows diagonal planking of the N.4 Atlanta built on the longitudinal system.

CONSTRUCTION—TYPE "F."

The construction of the "F" type is on the box-girder principle, with four longerons running right fore and aft. The keel, another fore and aft member, runs from the stern post right round the nose to form the stem and finishes at the gun ring. The keel and keelson combined with the floors form the backbone of the hull. I am of the opinion that the keel is of faulty design, for many boats were found to leak badly, partly due to the bad connection between the keel and bottom planking, and partly because the keel is too narrow. The keel and planking are fastened with only one row of brass screws which secure the bottom planking to the keel in the hulls of the F.3 type.

Another weak point is the discontinuity of transverse strength caused by running the timbers down to the keel and stopping them there, no provision really being made to hold the centre girder to the bottom planking or sides of the hull.

When the F.5 was designed, the keel was connected to the keelson by long "U" bolts which ran down the side of keelson and through the keel as in Fig. "A." In my opinion this design was so unsatisfactory that if it had been fitted to any boats they would not have been in commission very long before they leaked badly. This construction called for very careful workmanship, as only about $^1/_{32}$in. of wood was left between the side of keel and the bolt. Assuming the holes in keel had been bored very carefully and the bolt rammed home, which was securely fastened at the top of keelson by nuts in a small channel, as soon as the boat grounded, or was placed in a trolley, the thin strip of keel between bolt and side would have split, with the result water would have found its way up the side of bolt and into the bilges. Although this construction was so weak and did not lend to quick production, it was with great difficulty I was allowed to modify same to the usual simple boat practice of fastening the keelson to keel by brass screws.

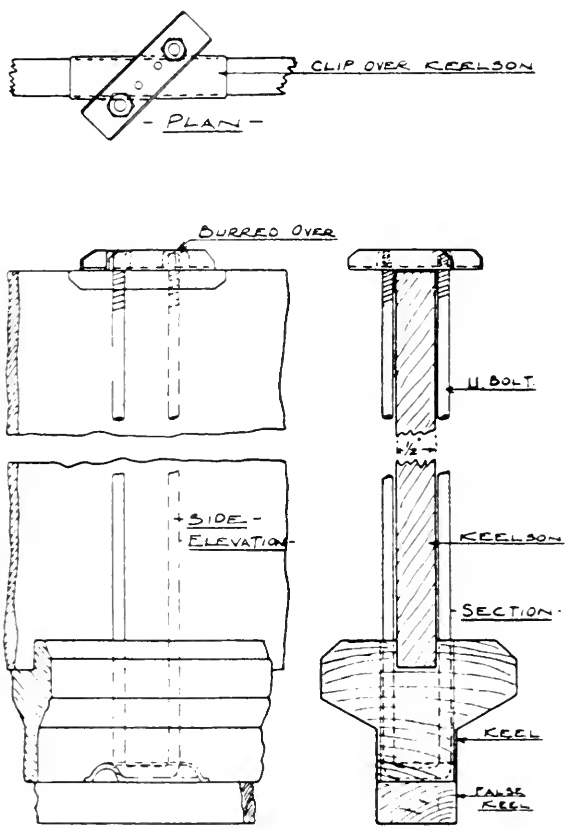
In the F.5 type, the timbers are continuous from fin chine to fin chine forming a much stronger combination. The keel was increased in depth to $1^{13}/_{16}$ins., the width being kept the same, namely $2\frac{1}{2}$ins. It would have been much better if the siding had been increased instead of the moulded depth. The bottom planking is again only fastened with one row of brass screws, which is

insufficient. However, a great improvement was made by the continuous timbers as they were through-fastened to the keel by copper rivets.

Keelson.—The keelson is fastened to the keel in the F.3 boats by brass screws 18ins. apart, but in the F.5 boats the spacing is 9ins., and the screws are hove up through the bottom of the keel. Although the keelson in some parts measures nearly 12ins. in depth, it is greatly weakened by having one third of the depth cut out to accommodate the floors.

Floors.—The floors in the F.5 boats have been cut away two-thirds of the depth, thereby sacrificing strength to accommodate the keelson. A built-up floor would have been much more effective, and probably about 40 per cent. lighter.

Timbers.—The timbers are of American rock elm, ½in. by ½in., spaced 4ins. apart amidships increasing to 7ins. at the ends of the boat and terminate at the



KEELSON BOLTS.

Fig. A.

lower chine; but it would have been an improvement had they been carried to the upper chine. The timbers are through-fastened to the keel by copper rivets.

Fin Top.—The timbers under the fin for the early F.3 hulls were heavy and widely spaced, but the later boat's timbers, ¾in. by $^5/_{16}$in., spaced 2ins. apart, were substituted to permit all through-fastenings of the diagonal planking on the hard wood timbers. It might also be stated here that the fin top of the first series of F. boats was three-ply birch, and in later types was covered with fabric and varnished. The introduction of diagonal planking was a great improvement on this system. All the fins on the F.3 class are flat, but on the F.5 type have ½in. camber, which adds to the strength, gives a better appearance, and assists in getting rid of water easily.

Stringers.—Two stringers, equally spaced from the fin member, run under the fin, and other two stringers placed immediately below these on the bottom are connected by ½in. square posts spaced 1ft. apart. Intermediate stringers,

16ft. long, are introduced in the fore part of the boat to further strengthen the shell and to absorb shocks when the hull alights on the water.

Fin Member.—In the first boats of the F. type the fin member was of American rock elm. On account of improper connection between the side of the hull and the fin top, the longitudinal seam naturally opened up, so in later hulls the fin member was constructed with the member and bead in one. This in turn might be improved by rabbeting out a piece at the back to allow the sides to house correctly.

Bow and Nose.—The timbers at the bow are of rock elm $\frac{1}{4}$in. by $\frac{3}{8}$in., spaced $2\frac{1}{2}$ins. apart, and are reinforced by horizontal stiffeners below the top longerons. These are spaced to take the outer seams of planking, tapered towards the stem and connected to the same by small oak breasthooks. These breasthooks bend the two sides of the bow together at the juncture of the stringer and stem, thus forming a very strong combination. Above the top longeron there are ten deck stringers which are notched to take the ribs, together with three strong beams which sub-divide the athwartship ribs. This skeleton, which is shaped like a dome, is planked diagonally, the inner skin being laid at 45 degrees with the forward ends of the planks lowermost. The outer skin is laid approximately fore and aft to suit the curve of nose. Each skin is of mahogany $^{3}/_{32}$in. thick, the planking being fastened to strong beams with wood screws. Where stringers and ribs occur, copper nails are driven through and fastened on grooves on the outer skin; elsewhere the planks are fastened with copper nails spaced about 1in. apart.

Sides.—Abaft the bow planking the sides are of three-ply birch and extend from the bottom of the fin member to the top longeron, running aft to the gun-port openings, a distance of about 18ft. The three-ply boards are butted against the side stanchions, thus saving butt straps. In the early F. types, the sides abaft the gun-port openings were built up of a narrow strip of mahogany, which formed a washstrake, with fabric stretched between same and upper longeron. The fabric proved not to be strong enough, so this system was superseded by $^{1}/_{16}$in. diagonal planking with nainsook between the skins. This planking was fastened to timbers running from longeron to longeron, spaced 2ins. apart, with one stringer midway running fore and aft. The new tail planking was a great improvement, although it added about 47lbs. to the weight of the hull; but experience has justified the change and extra cost. Several of the latest hulls have the sides covered with two-ply "consuta" made up of two pieces of very thin mahogany sewn together with flax thread, which is lighter than riveted work.

Bottom Planking.—This is arranged on the diagonal system, the inner skin being of cedar $\frac{1}{8}$in. thick at the ends and $^{3}/_{16}$in. thick amidships, fitted at an angle of 45 degrees inclination to the keel. The outer skin is of mahogany $^{5}/_{32}$in. thick forward, $^{3}/_{16}$in. thick amidships, and $\frac{1}{8}$in. thick aft, the planking being at an angle of 30 degrees with the forward end of the planks butting against the keel. This arrangement tends to diminish surface friction in wake of the seams. A layer of varnished fabric is fitted between the two skins making the structure very strong. The planking is fastened together with copper nails, and to the floors and stringers with brass screws. Along the keel and fin member it is connected with brass screws $1\frac{1}{2}$ins. apart.

In the earlier types of boats, the planking was 5ins. in breadth with the rivets widely spaced, but it was found that with this breadth the atmosphere affected such thin material and opening of the seams resulted. The planking was afterwards cut down to $3\frac{1}{2}$ins. in breadth. It was also found necessary to keep the rivets very close to the edge of the planks as there was a tendency for the planks to buckle. The bottom planking extends to the fin chine which runs from the bow for fully two-thirds of the length of the boat.

Top of Hull.—The transverse strength is made up of beams and arches combined with spruce stringers spaced about 7ins. apart. The deck aft is built and covered with fabric, and the stringers decreased to a minimum in order to keep the tail weight as low as possible.

Bulkheads.—These are four in number, each running from the top of the floors to a few inches above the top of the fin line. They are of $^1/_{16}$in. three-ply birch, stiffened by diagonal spruce stiffeners. The top of the bulkhead is stiffened by a capping piece of spruce. Where a bulkhead is in line with the floor, it is necessary to fit a packing piece between the floor and the bulkhead, except amidships, where the keel is practically horizontal.

Where elevator control wires pass through a bulkhead, a fabric stocking joint with brass washer plates on each side keep the bulkhead watertight, and where centre bracing struts pass through, a three-ply watertight collar is fitted.

Metal Fittings.—The chief elements of the structure, such as struts, pillars, beams, floors, wing root spars, etc., are held and bound together by light steel fittings of about 16 B.W.G.

The metal fittings were so numerous in the F. type that they had considerable influence on production, and I am of the opinion that they have been much overdone on these boats, while the opposite is the case on the N. boats. It would improve and cheapen the job considerably if a metal fitting were introduced at the ends of stringers and hatches, instead of the wood knees, which are not strong and take up much time to make and fit.

Bracing.—The longerons combined with the struts and stays form the principal superstructure of the hull above the fin top. From the nose to the gun port openings these vertical and diagonal struts are of spruce, moulded to give the greatest strength with lightest section. Abaft the gun-port opening to the stern-post the vertical and horizontal struts are 1in. mild steel tubes, braced diagonally fore and aft and transversely with 10 B.W.G. wire, all the wires being adjusted by turnbuckles. The tail of the hull is not too stiff in torsion, so adjustment with the bracing wires must be carefully carried out, and all the turnbuckles locked.

Wing Root Spars.—The wing root spars rank among the most important pieces of the structure. They are held in position at the sides and centre of the hull by heavy stanchions and struts. The centre bracing struts are slotted, let over the keelson to which they are bolted, the ends resting on the keel. This may not be considered good practice, as it compels concentration of thrust in a small area, resulting in some cases in springing of the bottom planking and fastenings. Until quite recently all wing root spars were of solid section, grade " A " silver spruce, but these are now laminated in two or three sections.

Outside the hull, and running fore and aft, six ribs of brasswood, all equally spaced from the longeron to the end of the spar, further strengthen and help to keep the spars in place. These ribs have two small stringers passing through them, giving firmness to the structure, which in turn is covered on top with three-ply birch, and on the bottom a fabric is stretched from the leading edge to the trailing edge, the whole forming the wing roots.

Interior of Hull.—The bottom deck is of sparred spruce boards, varying in width from 3ins. to 4ins., screwed to the top of the floors.

About amidships, where the petrol tanks are stored, the floors are shaped to take the tank stools and are specially stiffened and built up at the sides to form the tank cradles.

Steps.—The steps of the F.2a and F.3 boats are framed with ash bearers ½in. thick, and are 3ins. deep at the after edge, tapering to meet a board which runs off to a feather edge forward.

The bearers are spaced about 5ins. apart, and though fastened to the bottom planking, where the timbers come in the way, they also take the fastenings. The bearers are joggled to take the step timbers, which are of ash $\frac{3}{8}$in. by $^{5}/_{16}$in., spaced about 2ins. apart. The inner skin of the planking is of $^{3}/_{16}$in. cedar, and the outer skin of mahogany of the same thickness, both laid diagonally. The whole step is constructed at the bench, fixed in place, and screwed on to the bearers.

At the forward edge of the steps a 6in. copper band of light gauge covers the edge of the step, the forward edge of which is sunk into the bottom planking.

Trouble was experienced with the feather boards swelling, and in some cases coming away altogether, due to the "tearing" or frictional resistance of the water when the hulls were driven at great speeds just previous to their getting off. This was remedied in the F.5 boats by carrying the outer skin of the bottom right through from end to end of the boat. The outer skin abaft the back step was then put on and carried forward to a feather edge under the back step, while a short false inner skin was fitted over the usual step framing and then attached to the

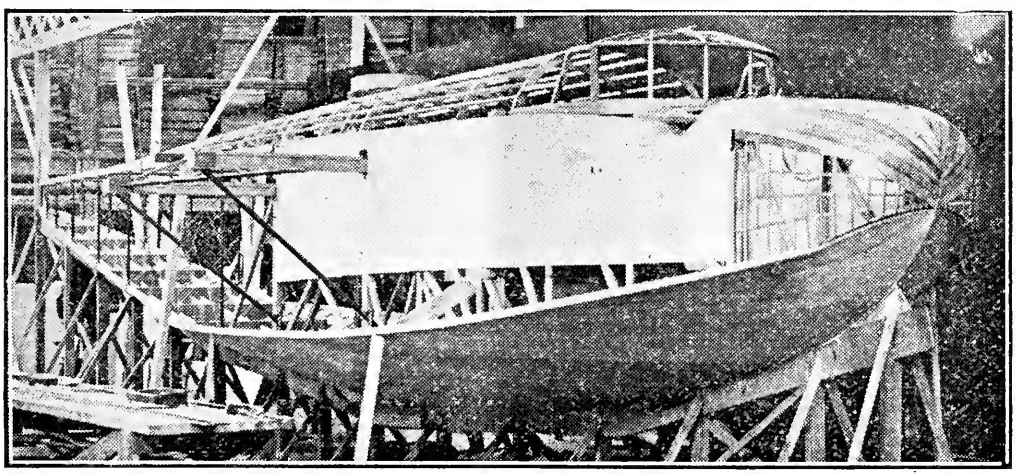


Photo No. 5.—View showing general construction of F3.

bottom skin. The outer skin between the steps was put on from the after end of the back step and worked forward to a feather edge under the main step with a false inner skin as before. The outer skin of the fore bottom was then carried right over this from the after side of the main step to the stem. This construction is much stronger and a great improvement on the former step.

Painting.—The inside, as far up as the fin top and the end of the tail, is coated with bitumastic paint, while the remaining portions are varnished.

Until recently the bottoms were varnished, and when the final coat was tacky, blacklead was rubbed in and the surface polished. This treatment is as applied on racing yachts, and has proved to be excellent, but as it involved a considerable amount of work at the stations, keeping the bottoms in good condition, it was superseded by black anti-fouling composition.

In some cases the anti-fouling composition has not proved very satisfactory, but as far as I am aware this is due to the builders not applying same properly. The paint should be stirred all the time it is being used, and again the boat should be put in the water before the anti-fouling is properly dry.

Another good protection to cover the bottom and fin tops would be velure paint, with a coating of varnish. This would be lighter than the blacklead and varnish, or the composition covering. The outside work not requiring paint is varnished, and should receive at least three good coats, occasionally being rubbed

down and revarnished. This is usually neglected with, of course, disastrous results to the material.

Two coats of black store enamel are applied to all the steel fittings. (See Photo No. 5, General Constructional View of F.3.)

TYPES "P." AND "N."

Generally the hull construction of the "P." and "N." types consists of a number of stringers disposed around the more or less circular section of the boat. Photo No. 5, General Constructional View of F.3.

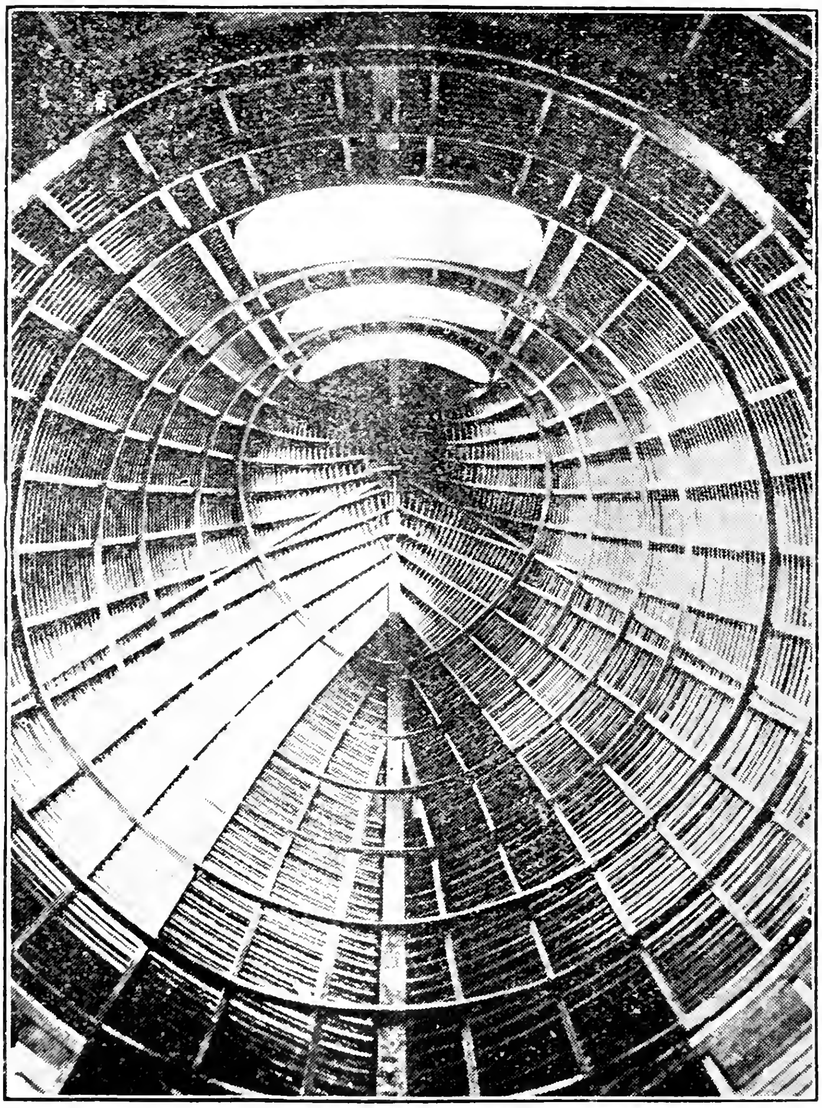


Photo No. 6.—The P5, showing circular section.

Stringers.—The longitudinal stringers are of spruce, $2\frac{1}{4}$ins., moulded at amidships, tapering to 1in. forward and $\frac{3}{4}$in. aft, all sided $^5/_{16}$in. All the stringers have a pair of spruce fillets at the bottom and a pair of similar fillets at the top, all of which are glued and fastened through the floors and skin. I suggest that these stringers and fillets should be worked out of the solid, forming a lighter and stronger "I" girder.

The stringers are secured to interior bent wood hoops of rock elm spaced at intervals apart and extending in planes transversely to the longitudinal axis. The hoops are doubled in wake of the spars alternately scarfed at the top and bottom.

Timbers.—Externally, around the longitudinal stringers, are a number of bent wood ribs or timber of rock elm, moulded $^5/_{16}$in., sided $\frac{3}{8}$in. and spaced 2ins. apart, except at the bow, where they are fitted as cant timbers and spaced $2\frac{1}{2}$ins. apart. All timbers are in one piece, bent right round the hull with the ends at the keel, into which they are joggled and glued to the stringers.

Floor Timbers.—The bent floor timbers are of rock elm, $\frac{5}{8}$in. moulded, sided $\frac{3}{8}$in. at the centre of the keel and tapered to $\frac{1}{4}$in. moulded and $\frac{3}{8}$in. sided at the ends, all of which embrace one-quarter of the hull, thus ensuring perfect transverse continuity of strength in the timbers.

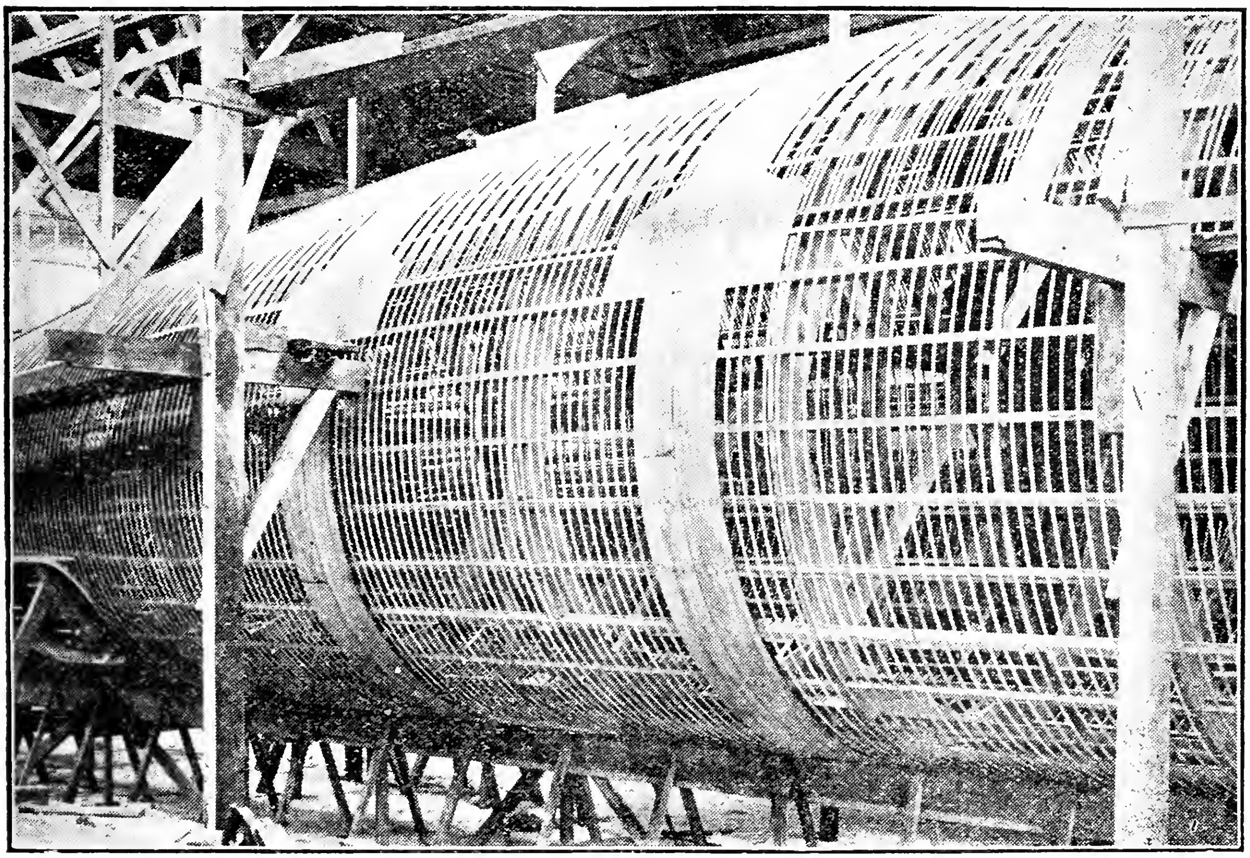


Photo No. 7.—The N4 Titania, showing timbers, stringers, and straps.

Keel.—The keel is of rock elm, moulded $1\frac{3}{4}$ins., sided 3ins. at amidships and tapered at the ends. It is in one piece and runs up to form the stem and is a great improvement on the construction adopted in the "F." type.

Keelson.—The keelson is of spruce, 5ins. moulded at amidships and tapered to stem on fore end and to 2ins. on after end. It is sided $\frac{5}{8}$in. parallel throughout. The bottom is carefully joggled over the floors and glued and secured to the keel by two spruce fillets, which are glued and through-fastened to the keelson, keel and floors. The top side of keelson is rabbeted into the underside of a top member or flange, which is secured by glue and screws. This top member or flange is of spruce, moulded $\frac{7}{8}$in. at centre and tapering to $\frac{3}{4}$in., sided $2\frac{1}{2}$ins. at centre tapering to stem forward and to $1\frac{1}{4}$ins. aft; the keel, keelson and top member forms a very strong "I" girder.

Sternpost and Saddle Straps.—The sternpost is of mahogany, 3ins. moulded and sided, which extends to 1ft. above the hull. Saddle straps of elm are fitted, those at the main spars and tail-plane struts are in one piece, running round the boat with their ends fastened to the keel, as in the case of ordinary timbers, and of the same thickness. (See Photo No. 7 for Timbers, Stringers and Straps.)

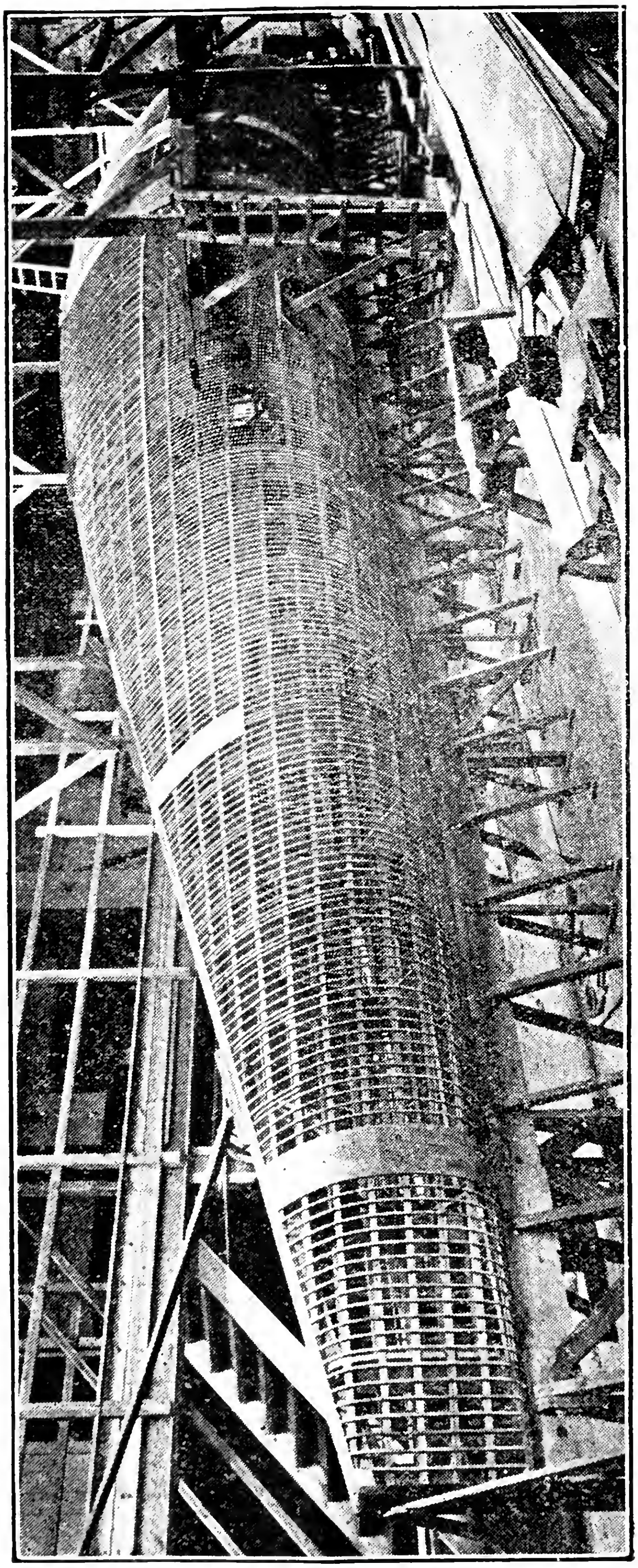


Photo No. 8.—N4. Complete hull in frame.

Doublers.—In addition, doublings of English elm are fitted at the wing root stay plates at front and rear spars. These doublings are carried in a fore and aft direction for a length of 30ins., carefully joggled over the timbers and floors. (See Photo No. 8, N.4 Complete Hull in Frame.)

Planking.—The planking is of Honduras mahogany fitted in narrow widths with close seams. The inner skin, $^3/_{32}$in. thick, being laid diagonally, the outer skin, $^3/_{16}$in. thick of the same material, is laid fore and aft. I am of the opinion this might be improved by fitting the diagonal planking 45° inside and 35° outside, and as the stringers run fore and aft, this would make a very strong job. The saving in labour would be considerable; roughly it might be stated if in the N.4 ten men took three weeks to do the outer skin fore and aft, eight men would do the same diagonally in two weeks. In the first case the wages bill would be, say, £150, and in the second £80, which shows a saving of nearly 50 per cent. One has only to consider the time spent in dividing out and in tapering and shaping the planks fore and aft to appreciate the above.

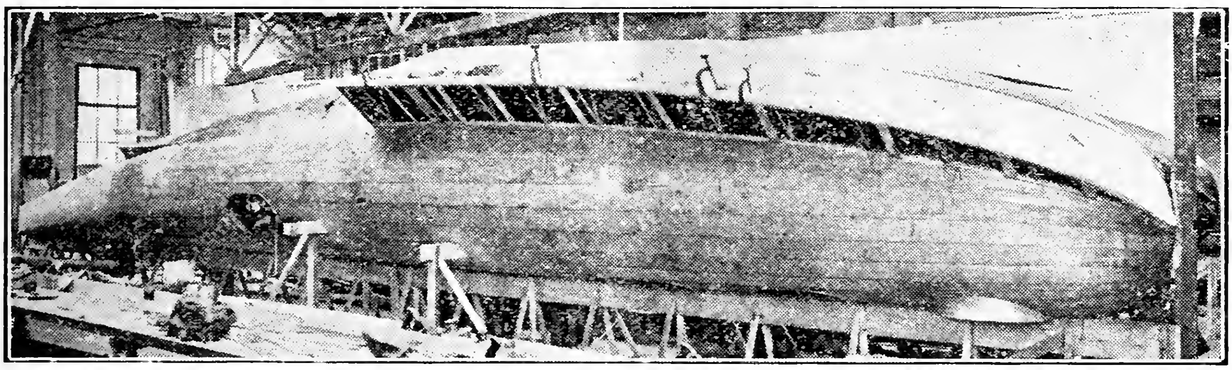


Photo No. 9.—P5, showing planking and steps.

Varnished nainsook is laid between these skins; this not only makes a watertight job, but is light and very strong. The inner diagonal skin is held in position with copper pins, the outer being through-fastened to the timbers with copper nails, the ends turned on the face of the timbers.

Steps.—Outside the main structure already described, a double bottom or water planing surface is fitted, known as the step. The water planes are framed up forward of the main step with three-ply birch and small stiffeners, the frames being spaced 18ins. apart and secured to the inner hull planing-bottom with spruce fillets.

The chine of rock elm is in one piece and tapered from $1\frac{1}{2}$ins. by $1\frac{1}{2}$ins. at the front step to $1\frac{1}{4}$ins. by 1in. at the stem. The stringers are of spruce all in one piece fore and aft, fitted through the three-ply frames, which are fixed to them by small fillets.

The timbers are of rock elm of the same size and spacing as in the main hull, the ends joggled into the chines and tapered to fit the hull. They are secured to the face of the stringers with glue and light copper pins. The bottom is planked with a double skin of mahogany with varnished nainsook between, similar to the main hull. (See Photo No. 9, P.5 showing Planking and Steps.)

Fin Top.—The fin top is framed with rock elm timbers spaced 2ins. apart, the ends being joggled into the chines and into a fillet of rock elm. The whole is planked in a similar manner to the inner hull, carefully fitted to the chine and hull-fillet rabbets and closely fastened with screws.

Protection Plates.—Rubbing plates of $^1/_{16}$in. brass, bent to the shape of the bottom, are fitted along the keel, and the chines are also protected by brass strips

fitted along the sides and bottom with the fore ends let in flush and secured by screws.

A strong point in favour of the small transverse framed hull is its resiliency, as it does not depend for its efficiency upon the rigidity of the parts comprising it. (See Photo No. 10, N.4 Interior View Looking Forward.)

Up to the present all flying boats have been built principally of wood, but Messrs. Beardmore have recently taken the next step towards advancement in building a composite boat. This is a stage in construction shipbuilders arrived at

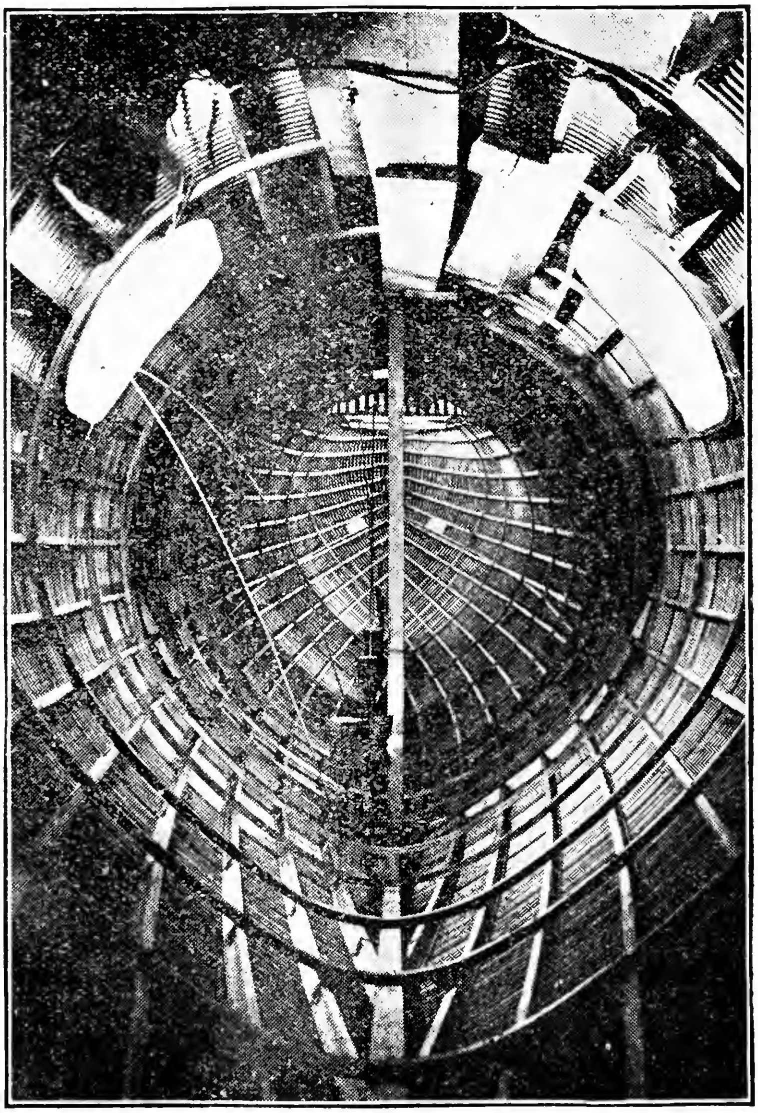
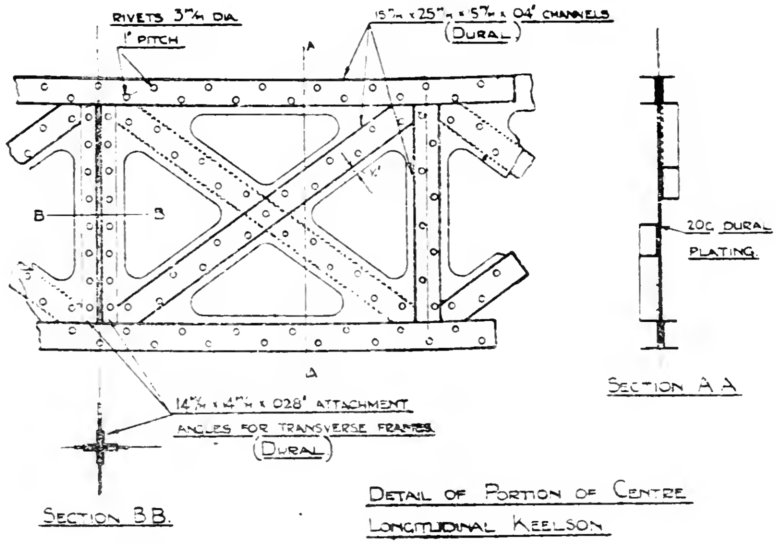


Photo No. 10.—The N4 Titania. Interior view looking forward.

many years ago, and at that time many problems had to be solved to get a satisfactory job. However, Naval Architects mastered all the problems, with the result many good composite boats are still in commission. The composite boat known as "W.B.IX.," built by Beardmore, is on the longitudinal system, the main portion of the hull being of approximately circular form. There are 17 continuous longitudinals, which run right fore and aft, care being taken that none of these members are cut throughout their entire length. The seven longitudinals on the lower side of the hull are built as shown in sketch 1, and the remaining longitudinals on the top side are built as shown in sketch 2. The channels forming these longitudinals are of duralumin 25mm. x 15mm. x 15mm. x .04ins. thick, and are braced as shown in sketches 1 and 2.

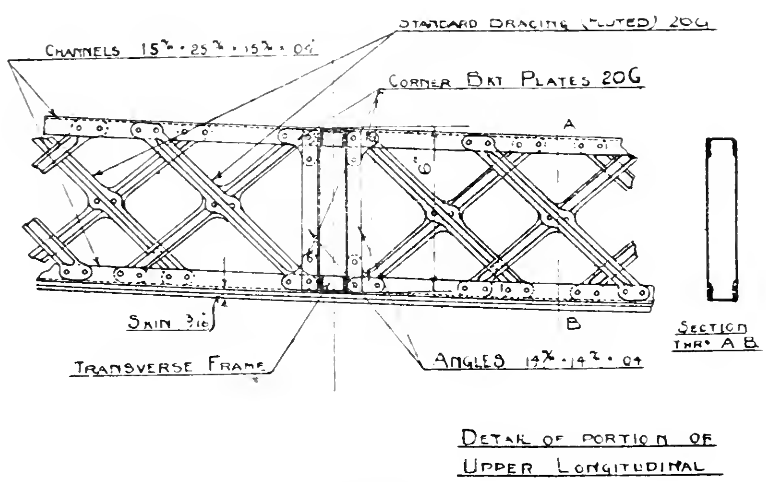
The main transverse frames are intercostal between the fore and aft longitudinals and are spaced along the boat at approximately 2ft. apart. (For construction see sketch 3.)

The channels forming the transverse frames are the same size as those in the longitudinals. The transverse frames are connected to the longitudinals by duralumin double angles 14mm. x 14mm. x .028ins. and gusset plates of .04ins. thick.



Sketch 1.

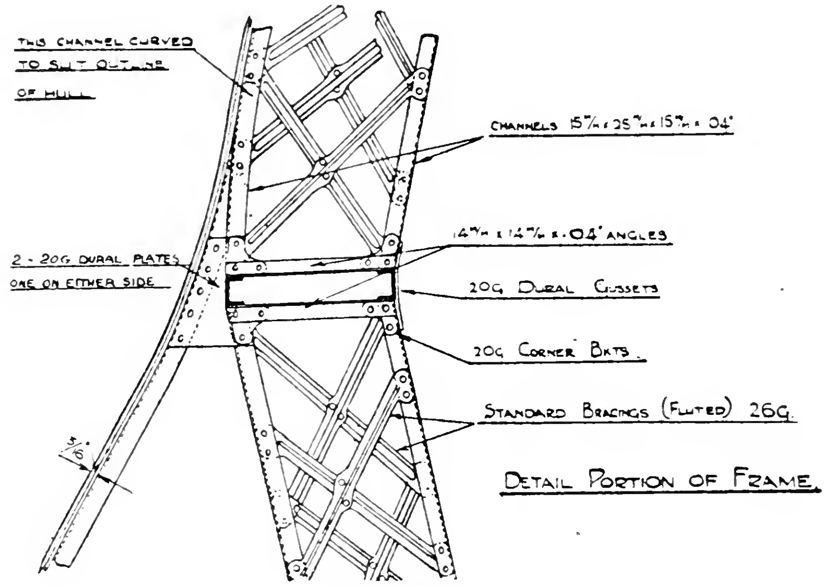
The framing from keel to chines and from chines to hull side is formed of duralumin channels 25mm. x 15mm. x 15mm. x .04ins., this framing being braced and supported to the main portion of the hull by duralumin channels and gusset plates.



Sketch 2.

Intermediate transverse framing is fitted from chine to keel and keel to chine on the bottom of the boat, the spacing of these transverse frames being approximately 8ins. Intermediate longitudinal frames are also fitted approximately 6ins. apart, the latter framework forming a support for the skin of boat. These intermediate transverse and longitudinal frames are formed of light duralumin channels .033ins. thick and .04ins. thick as required. The intermediate transverse and longitudinal framing on the top of the boat is of similar construction to that on the bottom, the framing at this part forming 8in. squares of the same section of channel.

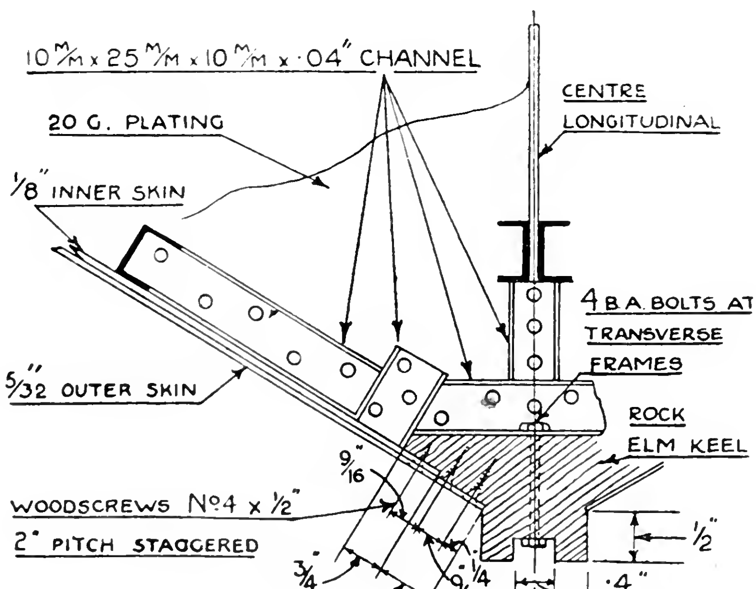
The continuous main longitudinals run right forward and finish into a heavy transverse nose frame built of duralumin channel and plate, thereby forming a very rigid structure forward. In front of this frame the nose of the boat is made of a removable steel nose cap which can be removed and replaced in the event of damage.



Sketch 3.

The keel and chines are of American rock elm and are double rabbeted to take the two-ply skin. (See sketches 4 and 5.)

This double rabbet is a great improvement over the method adopted in the F. boats, but the chine piece would have been better if a greater distance had been left between the edge and end of planking.



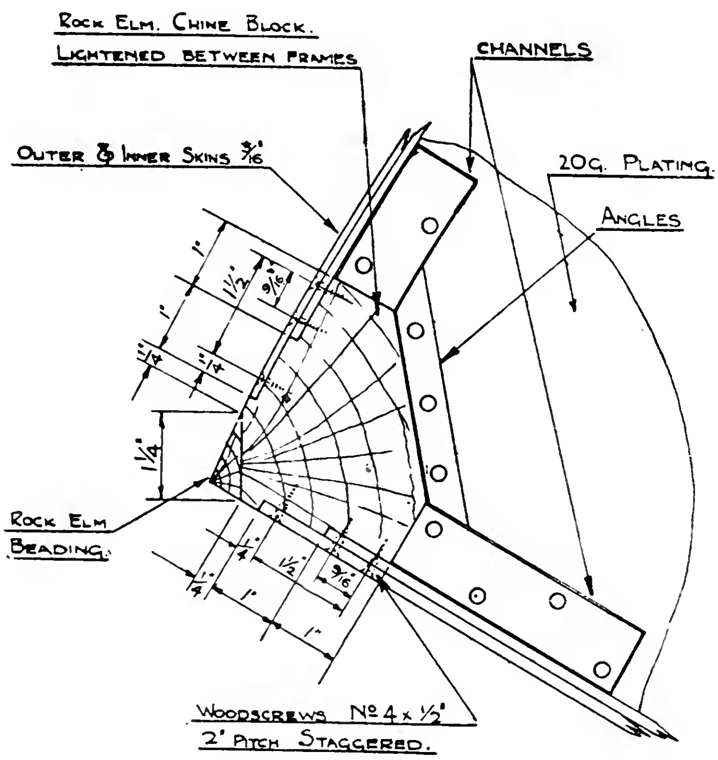
Sketch 4.

The skin below the chines is formed of two thicknesses of mahogany planking, the inner thickness being $\frac{1}{8}$in. laid at an angle of 45°, and the outer thickness $^{5}/_{32}$in. laid fore and aft. One ply of varnished cotton fabric is laid between the mahogany skins. The skin is fastened to the duralumin framing by $^{1}/_{16}$in. dura-

lumin nails clenched over rooves in the inside of the hull. The two skins clear of the framing are rivetted together with similar nails clenched over rooves. The skin above the chines is of two thicknesses, each $^3/_{32}$in. mahogany, the inner thickness laid at 45° and the outer thickness fore and aft, with varnished fabric between. Attachment to framing is similar to that of the bottom skin.

The builders have avoided many of the mistakes the early constructors made in the fastenings, as for instance in some of the F.3 boats there were only about 60 rivets per square foot; but I am of the opinion Beardmore have overdone the fastening, as they have about 160 rivets per square foot in the skin.

The framing-in way of the step is of wood and consists of eight $\frac{1}{2}$in. elm fore and aft formers and 23 $\frac{1}{2}$in. by $\frac{3}{8}$in. rock elm transverse formers each side of centre line with finishing transverse former at rear end of step $\frac{5}{8}$in. by $\frac{5}{8}$in.



Detail Section of Chine.

Sketch 5.

rock elm. The step is open to the sea, no attempt having been made meantime to provide watertightness.

Six $2\frac{3}{4}$ins. diameter vent holes spaced 15ins. centres are provided on the bottom of the hull, just aft of the step, to ventilate same. These vent holes are led into a common pipe, one on each side, and led out from skin about 15ins. above the load water-line. Watertightness is provided where the vent pipes go through the hull bottom by rubber rings and dished washer plates, the end of the pipe being spun over on the outside.

The sternpost is of duralumin 2ins. by 1in. solid in section faced on each side by elm blocks, to make up the line of hull. From the sternpost forward 1ft. 10in., in the centre of the boat, duralumin plating is fitted from keel to top, reinforced with duralumin channels to provide for landing shocks in way of rear skid.

The engine-bearers are built of duralumin channels and plates and are placed on the main fore and aft bottom longitudinals to distribute the load over the hull.

There are three watertight bulkheads fitted in the length of the boat.

A hand-winding anchor gear is provided in the nose, the cable being led through the fore foot; the structure being suitably reinforced in the vicinity and a watertight cable guide provided.

In order to prevent corrosion, the whole of the duralumin framework is coated with oleo resin asphaltum varnish, this being done during construction in order that all joints are well protected. Inside the boat, in way of the engine room, there is an additional two coats of paint composed of graphite and tung oil varnish.

The whole structure is enormously strong, in fact too strong for the work it has to perform, with the result that the hull is much too heavy. The framework is so rigid that the boat could at any time be completely replanked without distortion to the shape of the general lines.

This boat has not yet been tested, but I am afraid the rigidity of the hull will prove to be one of the weak points in the design. The details and general workmanship are very good and show a great improvement on many of the service boats.

SUPERMARINE FOUR-SEATER.

The construction is such that the hull is capable of resilient distortion, so that when alighting on the water or when subject to other forces the hull can spring, thereby materially reducing the effect of the shock.

The cross section is egg-shaped, being very light and yet possesses great strength. The hull is built up of longitudinal stringers with bent hoop timbers inside and light frames outside the stringers with double planking outside the light frames, all these being through-fastened together.

The stringers are recessed to take the light frames, thus giving a good faying surface for the skin. The keelson constitutes a stringer, as it is of similar section.

One of the principal features of this design is that no web frames or cross-bracings are required. The hull is a continuous structure, so that the steps are built on to the skin planking. The top of step is connected to a longitudinal fin member, while the bottom is secured directly by small timbers to the hull. The fins are supported inside by thwartship cross members, small bulkheads and longitudinal members, to give the requisite strength for this member.

As many of the sections are of similar design and construction, this lends itself to quick production. All the stringers can be run out in the mill, also the timbers, thus a fair percentage of the work can be executed in running lengths, this being a great improvement on the construction of the "F." type, with so many different sections and details which require to be done by hand.

If these boats are being built in numbers, all the planking can be cut in pairs. The diagonal planking being parallel and of equal thickness, can, together with the stringers, timbers, etc., be made stock sizes and issued out in lengths from the store.

As a commercial and production proposition the following are the outstanding features:—

The reduction of raw material to mahogany, rock elm and spruce, brasswood, screws, copper nails and rooves, fabric, marine glue, black varnish and boat varnish, the first of which can be converted into $\frac{1}{8}$in. planking of convenient lengths and widths ($\frac{1}{4}$in. $\times$ $\frac{1}{4}$in., $\frac{3}{8}$in. $\times$ $\frac{3}{8}$in.), or $\frac{1}{2}$in. $\times$ $\frac{1}{2}$in. rock elm timbers into suitable lengths, stringers of spruce into suitable lengths, and be issued out on the job as required or in suitable quantities for the construction of each hull.

Take a hull of 35ft. in length, you can employ one class of labour only, for instance—boatbuilders; a small number of men and boys can be placed on this job, and if piece-worked, with the exception of supervision and inspection, the chances of hold-up through materials are so small, owing to there being no complication, that they can carry straight through and finish their job. Compare this, for example, with a flying boat of the F.3 or F.5 type. You have to start criticising this at the ordinary commercial proposition, in the first instance, of storekeeping. You run into such items as turnbuckles, bolts and nuts, wires, cables, sheet steel, steel tubing, in fact a hundred and one parts that go to the building of a large aeroplane's fuselage. You must employ not one trade but quite a number, such as boatbuilders, carpenters, sheet metal workers, fitters, machine hands, wiremen, riggers, and are immediately in the midst of demarcation troubles, allocations and arrangement of working squads, processing in a dozen different ways; your inspection costs go up in many details, all of which are liable to hold up the job—even a small point if turned down in inspection can completely stop the job for days on end—and if the question of finished stores is not a highly organised one, a small bolt and nut, wiring plate, etc., going adrift means a stoppage. Stoppage means money, and invariably these stoppages occur which, apart from their own cost, lower the moral of the particular men who are working for completion on the job. Without going into further detail, the foregoing, I think, points out the advantages and disadvantages of the two types from a construction point of view both from ease of construction, expense and on-costs.

During the recent year the Supermarine Company have patented a flexible bulkhead. Owing to the work of the hulls when in any kind of sea-way, it is impossible to make rigid fastenings to the hull, in fact if this is done the object of the flexible hull is at once destroyed, and if heavily strained the same experience is found in light racing launches, the hull, although not breaking at the bulkhead, throws itself out or splits several feet away either in a forward or aft direction. If it is therefore desirable to bulkhead a resilient hull, this must be of a flexible nature.

After considerable experiments had been carried out a suitable type was used with every success, its nature being of double diagonal planking in between and round the edges of which was fitted heavy canvas, marine glued and through-fastened. Where this is to be fastened to the hull an inside timber or hoop is laid round the stringers and through-fastened to the stringers; a padding piece is laid between the hoop stringer and the skin, also through-fastened, forming a complete register round the hull. The bulkhead, complete with canvas collar, is then laid in the hull, the canvas necking assuming a "Z" shape in section on either side of the bulkhead. The bulkhead is then secured by floating cross members which allow the whole of the bulkhead to float in any direction or the hull to move in any direction round the bulkhead to an extent of about 2ins. on any diameter.

The arrangement of experimenting tests were carried out in an ordinary barrel, by stand pipe and water pressure, being fitted between the sound end of the barrel and the bulkhead, the other end of the barrel being removed.

Another Supermarine feature is the question of the step. All hulls constructed and designed by the Supermarine Company have built on fore and aft steps of a watertight nature. Each step is divided into two complete halves on the port and starboard side of the main keel proper, and each half is again divided into four separate watertight compartments. On these boats the steps continue or protrude a considerable distance forward of the hull proper. This protruding portion of the lower step is divided up by a collision bulkhead forming a fore peak, which in case of ramming any floating object, carries away the forward part of the step which is always out of water, and the chances of damaging the hull proper or the flotation part of the step are practically nil. The rear steps are also

divided into watertight compartments, the main object being in case of the step being holed or severely damaged, the chances of failure are 8 to 1, and anyway the design allows for the steps to be filled with water and then not to endanger the buoyancy of the boat to any extent which would be dangerous.

A further point is in case of bad damage the main circular part of the hull is not scrapped. The boat can be put into dry dock and have a complete new step built on it, which is a matter of great importance, both in war-time and from a commercial point of view.

The following facts may be of interest:—

Supermarine standard four-seater hull, 31ft. in length, takes three men and two boys on an average $5\frac{1}{2}$ weeks to build, working on a 47-hour week. This type of hull, however, can be manufactured, if it is a question of saving time, in considerably less periods; for example, for the aircraft for the Martlesham amphibian trials the Supermarine Company designed and completed a flying boat in all respects in 10 weeks from the time when the first drawing was commenced to the time the aircraft was in the air, the actual hull building time being $4\frac{1}{2}$ weeks. This hull was considerably bigger than the standard type of Supermarine construction.

It is worthy to note that during the firm's trials at Southampton this aircraft landed in a ploughed field, with furrows of about 15in., which not only pulled the amphibian up in a very short distance, but owing to the heaviness of the ground, threw the boat forward on its nose, leaving the section of the hull on the earth for a distance of about 15 yards. The boat was dropped on its tail, which also speaks of the rigidity of tail construction, to put up with such treatment, and was flown off and landed on Eastleigh Aerodrome, no damage of any kind, with the exception of scratched varnish, was experienced, and later during the trials the aircraft was often tripped in this manner by the pilot for turning purposes. Battens had been fitted in the fore part of the boat as rubbing strakes.

It was also definitely proved that the fear now existent with land machines of turning over at the bow in landing on heavy ground is not to be experienced by amphibian machines, while dropping the aircraft from its right forward position to down, resting on its tail skid, can give some idea of the strength of the hull construction.

It is to be noted in this particular type of hull that the rudder post or skid post is not at the end of the ship, but about 5ft. forward from the sternpost, which proves that this kind of construction can take immense loadings on small bearing areas or surfaces.

These hulls have proved to be very strong, as I have seen a 13-stone man jump several times from the engine-bearers on to the top of the hull without damaging it in the slightest way. The torsional strength has also proved to be good, as the same man was swinging at the tip of a 16ft. span tail plane which only gave approximately $1\frac{1}{4}$ins. deflection.

The same boats have often been stalled from heights up to 30ft. without showing the slightest damage to the hull. The foregoing are only a few of the severe and trying tests the hulls have been subjected to, and throughout they have shown themselves to be wonderful. The main and outstanding feature of the Supermarine hull is not an aeroplane that will float but a seaworthy boat that will fly.

I believe the Specification Committee of the Air Ministry have prepared a glossary of technical terms for general aircraft, but as far as I am aware have not included the technical terms used on flying boat hull construction. It appears to me this deficiency should be remedied, as several of the aircraft constructors have often asked me to define many of the Naval Architects' terms. I have endeavoured to fill this want, so have added as an appendix to this Paper the

general shipbuilders' terms as applied to flying boat hulls. I am aware the list is by no means comprehensive, so hope the members of this Society will ask for the terms they wish defined, or assist me in making the list complete.

APPENDIX "A."

GLOSSARY OF TERMS USED IN FLYING BOAT HULL CONSTRUCTION.

Afterbody.	The part of a boat abaft the midship section.
Alleyway.	Fore and aft passage under deck, or hood.
Amidships.	The centre fore and aft line of a boat.
Apron.	A piece of timber fitted to aft side of stem to form backing for plank ends.
Athwart.	Transversely, at right angles to fore and aft.
Base Line.	In N.A. a level line near the keel, from which all heights are measured perpendicular to it, sometimes called datum line.
Beam.	The transverse member to support the deck, and tie sides. The breadth of a boat.
Beam and Length.	The proportion of a boat's beam bears to her length varies according to her type.
Bilge.	The round in a boat's timbers or frames where they begin to approach a vertical direction.
Bilge Keelsons.	Stout pieces of timber or metal sections fitted inside a boat in a fore and aft direction along the bilge to strengthen her longitudinally.
Bilge Strakes.	Planks or plates worked longitudinally forming outer skin along the bilge, or over the heads and heels of the frames.
Bilge Water.	The water inside a boat, which lies in the bottom.
Blisters.	Unsightly bladders on paint are generally caused by putting new paint upon the top of old, or using very thick paint.
Boat Chocks.	Wood members cut to shape of thwartship section of boat where fitted.
Body.	Part of a boat's hull, as fore-body, middle-body and after-body.
Body Plan.	The plan which contains the cross sections of a boat's lines.
Bottom.	Usually understood as the part of a boat below the water line.
Box Scarf.	A method of joining two pieces of timber by letting each into the other one-half its own thickness.
Bulkheads.	The athwartship partitions which separate a boat into compartments, etc. Fore and after partitions are also termed bulkheads.
Bulwark.	The side of a boat above the deck.
Butt.	The joining or meeting of two pieces of wood endways. Butt and butt means that two planks meet end to end, but do not overlap.
Buttock Lines.	Planes in a fore and aft direction, showing the outline of vertical fore and aft sections.

Boot Top.	The portion of the surface coated with anti-fouling composition above the water level.
Battens.	Temporary fore and aft members around which the timbers are bent.
Bollard.	A vertical post, or fitting forming posts, in wood or metal for making fast cable, etc.
Breasthook.	A strong wood or metal knee fitted horizontally to stem.
Buttstraps.	A wood or metal doubling for connecting end of planks, or strakes of plating.
Cambered.	When the keel, deck, or fin top has its ends lower than its centre.
Cant Frames.	The frames in the bow and quarter of a boat that are not square to the keel.
Carlines.	Members fitted in way of deck openings, *i.e.*, half beams.
Carvel Built.	Built with the plank flush edge to edge.
Chine.	Where the top sides meet the bottom at an angle.
Clamps or Cramps.	A type of wedge vice, used in boat building to hold the planks together. Various contrivances of wood or metal used in fitting up a boat or in fixing parts in her construction.
To Clench.	To beat the end of a rivet until it forms a head, or to turn the end of a nail in so that it will not draw.
Cockpit.	A form of well in the deck.
Copper Fastened.	Fastened with copper nails or rooves and nails.
Caulking.	Driving cotton or other stopping into the seams, or in metal, clenching over edges to make watertight.
Ceiling.	The inside lining.
Coamings.	A raised frame fitted to and above the deck for hatches, or other openings.
Chain Girth.	The shortest distance measured round the hull from gunwale to gunwale.
Chain Plates.	A metal fitting rigidly attached to the hull to take shrouds.
Collars W. T.	Metal, wood, or other fitting round stringers, etc., where they pass through bulkheads or decks to make same W.T.
Composite.	The form of hull in which metal and wood construction are jointly used.
"D."	The capital letter "D" is used by naval architects to denote the displacement or total weight of the boat and her equipment, generally expressed in pounds or tons.
Dead Wood.	The solid wood worked on top of the keel forward and aft.
Deck.	The platforms supported on the beams.
Doubler.	To put one thickness of plank or plate over the other.
Dowel.	A hard wood or metal pin used for connecting timber on the edges of planks.
Dump.	A nail used in fastening plank to the timbers, as distinguished from a through bolt.

Draught or Draft.	The distance between the lowest portion of the boat and the L.W.L.
Diagonal Ties.	Strengthening members, which are fitted at an angle to the stringers or beams.
Entrance.	The fore part of a boat, the bow. A good entrance into the water means a long well formed bow.
Fairing.	A process by which the inter-sections of curved lines with other lines in the body plan, half breadth plan, and sheer plan are made to correspond.
Fairleads.	Holes in plank fittings or metal for ropes or wires to lead through, so that they run fairly and are not nipped or formed into a bight.
False Keel.	A piece of timber or metal fitted under the main keel to deepen it.
Fastenings.	The bolts, nails, etc., by which the framing and planking are held together.
Fay, to.	To join pieces of timber together very closely. Plank is said to fay the timbers when it fits closely to it.
Feather Edge.	When a plank or timber tapers to a very thin edge, "Tapering to nothing."
Fender.	A buffer made of rope, wood, matting, cork, or other material to hang over the side of boat when she is about to come into contact with another boat or object.
Floors.	Transverse members connecting the heels of frames to bottom and keel.
Flush Deck.	When the deck has no raised or sunken part.
Fore body.	The fore part of a boat which is forward of the midship section.
Frames.	The transverse members to which the skin is fastened.
Freeboard.	The distance from W.L. to gunwale.
Flare.	When the breadth at the gunwale exceeds the breadth at L.W.L.
Fillet.	A packing or distance piece.
Filling.	A stopping for seams, etc.
Flat-Floored.	When the timbers and floors project from keel in a more or less horizontal direction.
Fore Foot.	The foremost part of the keel at its inter-section with the stem.
Foot Rails.	Fore and afters of hard wood or metal fitted to deck to give foothold.
Floor Boards.	A light decking inside the hull.
Fore Peak.	A compartment next the stem.
Futtocks.	The timbers which abut above the floors.
Garboard.	The strake of plank, or plates, next above the keel into which it is rabbeted and bolted, or riveted.
Grummet.	A ring formed of a single strand of rope laid over three times.
Gussets.	A connecting piece.
Gunwale.	The fore and after at the extreme breadth under deck.
Gratings.	Open wood work on bottom for decking.
Gripe.	The fore part of the dead wood.

Gudgeons.	Metal eyebolts fitted to the stern post to receive the pintles of the rudder.
Half-Breadth Plan.	A drawing showing the horizontal sections or water lines of a boat by halves.
Hanging Knee.	Knees that help to keep the beams and frame together, one arm is fastened to the under side of a beam, the other to the frame.
Harpings.	Pieces of timber or battens that are fitted around the frames in an unbroken line to keep the frames in their places before the planks or plates are put on.
Hatches or Hatchways.	Openings in the deck.
Hatchway Coamings.	The raised frame above the deck upon which the hatches or hatch covers rest.
Heel.	The lower aft end of anything as heel of the frame.
Hogged.	The form of a boat when she has combered sheer.
Hogg Piece.	A piece of timber worked upon top of keel to prevent its hogging or rising in the middle.
Hull.	The boat as distinct from her superstructure.
Half Beams.	Beams that are cut to take openings.
Hawsepipe.	A pipe fitted through the top sides to form a fairlead for mooring rope.
Hold.	Space for stowing cargo.
Hollow Lines.	The horizontal lines that have deflections.
Intercostal.	Fore and afters fitted against the stem which are cut at the floors.
Joggle.	A notch or notches forming a box scarf to enable two pieces of wood, etc., to fit together. In metal boats where the one plate, or metal, overlaps the other, giving an inside fair surface.
Keel.	The fore and aft members in a boat to which the frames and garboard strake are fastened, or if a diagonal planked boat, where the planks end.
Keelson.	An inside keel fitted over the throats of the floors.
Knees.	Pieces of timber or iron shaped to strengthen particular parts of a boat. A hanging knee is the one fitted under the beams; a lodging knee is a knee fitted horizontally to the beams and shelf or deck beams. Floor knees are V-shaped like breast hooks.
King Plank.	Centre plank of deck.
Lines.	A general term applied to the drawing or design of a boat as depicted by fore and aft lines and cross sections. A boat is said to have "fine lines" when she has a low block coefficient.
Load Water Line.	The line of flotation when a boat is properly laden or ballasted.
Lap.	The edge of one plank over the edge of another.
Locker.	A receptacle built into the boat.
Limber.	A waterway.
Moulded.	The thwartship dimension of timber or frames.
Moulded Breadth.	The greatest breadth of a boat without the plank,

Moulds.	The skeleton templates to cut the frames by, or to hold the boat in shape while the timbers and stringers are being fitted in place.
Manhole.	A circular scuttle, the minimum diameter through which a man can pass.
Mould Loft.	A building in which the floor is painted dull black, and is used for laying off lines full size.
Midships.	The centre of fore and aft lengths.
Mast Step.	The chock in which the wireless mast is housed.
Mortise.	A cut groove at a joint to take tenon.
Overhang.	The ends of a boat, which at the gunwale extend over the water, *i.e.*, L.O.A. exceeds L.W.L.
Overheads.	Beams, moulding, etc., forming ceiling under deck.
Parcel.	To cover a rope with strips of canvas painted or otherwise. The canvas is wound round the rope and stitched or "served" with marline.
Pintles.	The metal hooks by which rudders are attached to gudgeon sockets.
Planking.	The outside skin of a boat; plank laid on the frames or beams of a boat whether inside or outside.
Plank Sheer.	The outside plank at the deck edge which reaches the timber or frame heads, and shows the sheer of the boat.
Port.	The left hand side of the boat looking forward.
Partners.	A doubling between beams to take deck fittings.
Pillar.	Vertical supporting members under deck.
Quarter.	Top sides between full abeam and aft centre line.
Rabbet.	An angular channel or groove cut in the keel, stem or sternpost, etc., to receive the edges or ends of the plank.
Ribands.	Long pieces of plank or timber, sometimes called harpings, secured to the frames of a boat in a fore and aft direction, when she is building, and representing the dividing lines or geodetic lines.
Ribs.	The frames or timbers of a boat.
Rake.	At an angle to the vertical in a F. and A direction.
Risings.	A fore and aft by which seats or other items are supported.
Rail.	The extreme F. and A. top line above water.
Scantlings.	The dimensions of all material used in the construction of a boat.
Scarph or Scarf.	A method of joining pieces of wood or metal by tapering their ends. A box scarph is when the ends are not tapered, but a half thickness cut out of each part so that when put together the parts form only one thickness.
Seam.	The line formed by the meeting of two planks or plates.
Shift of Butts.	The fore and aft distance between the ends of one line of plank or plate and that of the next below or above.
Side Keelsons.	Stiffeners fitted fore and aft on either side of the keel.
Skin.	The outside or inside planking of a boat.
Starboard.	The right hand side of the boat looking forward.

Stem.	The forward vertical continuation of the keel.
Step.	A planing surface built in or on the bottom of hull.
Stringer.	Strengthening fore and afters connected to frames or timbers.
Scantling Section.	A drawing of mid-section of a boat on which all scantlings of same are stated.
Scupper.	A freeing port.
Sole Beams.	Thwartship beams, supporting flooring.
Strake.	A fore and aft line of plank, or plating.
Sheer Strake.	The top line of planking or plating.
Sheer.	Fore and aft curve of gunwale.
Shelf.	A fore and aft member round deck inside planking to which timbers and beams are attached.
Sheathing.	Metal or wood skin fitted outside planking for additional protection.
Skin Girth.	The distance measured round planking from gunwale to gunwale.
Scuttle.	An opening which can be made W.T.
Stopping.	A substance used for making seams W.T. when not caulked.
Sternpost.	The vertical member where the planking terminates aft.
Siding or Sided.	The fore and aft dimensions of timbers, beams, etc.
Stopwater.	A soft wood dowel driven through dead wood at joint of same.
Spiling.	A method of setting out a curve from a straight line.
Through Bolt.	Through fastening. Fastening that ties several thicknesses of material.
Timbers.	The transverse ribs of a boat.
Transom.	The frame at the sternpost of a boat. The transverse board at the stern, which gives shape to the quarters and forms the aft end of the boat.
Transverse.	Athwartships. At right angles to the line of keel.
Tie.	Diagonal connecting and strengthening member.
Tumblehome	Where the extreme breadth exceeds the breadth at deck.
Topsides.	The upper part of hull above W.L. excluding stem and stern.
Turtledeck.	A deck with excessive camber.
Trim.	The fore and aft inclination of hull about L.W.L.
Thwart.	A seat forming tie across the hull in the absence of beams.
Tenon.	A tongue at the end of a timber to fit into a mortise.
Throat.	The distance across the flat of a knee.
Timber Heads.	The upper ends of the frames.
Tuck.	Where hollow occurs in the form of the stern or quarters.
Ways.	Baulks of timber on which the cradle slides.
Well.	A sunken part of the deck usually termed cockpit.
Waterways.	Apertures to allow water to flow to bilge suction.
Waterplane.	The horizontal area of hull at water line.

DISCUSSION.

Wing Commander T. R. CAVE-BROWNE-CAVE said he felt singularly unfitted to open the discussion as he had only come to obtain information and could only speak on very general lines. He was sorry Capt. Nicolson did not speak more on the question of design, but he had given so much information on construction that it was obvious the design side had to be left out. Were the bulkheads the Lecturer advocated effective with the high load pressures one got when a boat was moving rapidly over the surface of the water or were they simply strong enough to be effective when it was at rest? On what tests were the merits of the various types of construction judged? With ordinary aeroplane construction different types could be tested by sand loading. He did not know whether sand loading for flying boats was sound, but if so he would be interested to know how the types of construction which had been compared came out under tests. It seemed to him difficult in dealing with flying boat problems to know exactly in what respect one construction was better than another. The man who departed from accepted naval architects' practice was going to have great difficulty in making his case unless there was a definite test to which he could appeal. If, for instance, a sand-loading test were recognised as being a good one, the two methods of construction could be practically compared. If there were no direct test one was inclined to be prejudiced in favour of the accepted construction which had been built up as the result of long practice. Capt. Nicolson threw no light upon the effect of size. All those who had thought seriously of the future of aircraft must realise that the very big machine was going to be a boat or amphibian, and consequently they wished to know what kind of problems became more and more difficult as the size increased. If one went to a really large boat, would the Author's view as to the best construction be modified?

Captain W. H. SAYERS said he knew very little about flying-boat work, but he knew one or two things about the history of the flying boats. No doubt Capt. Nicolson was right in his criticism of the design of those hulls, as boats, but after all they were parts of a flying machine, and they were constructed by people who were not naval architects, and who received no encouragement from naval architects, and who set out to make something fly. They made it fly, and laid the foundations of the flying boat industry. They deserved a great tribute of praise for fighting through the enormous difficulties they had to face and making something which, after all, floated on the water and flew in the air. It was some time after the flying boat had flown before any naval architect attacked the design of flying boat hulls and made one which flew, with the exception of the Sopwith Bat boat, and that was an entirely different proposition to the flying boat of the present day.

Mr. W. O. MANNING expressed his appreciation of the Lecture. The criticism of the different points of flying boat construction by a trained naval architect was one of the most useful things that could be brought before the flying boat industry. He thought that there was no doubt that the ordinary straightforward principles of boat building must be adopted in flying-boat work. All experience up to the present showed that the resilient type of boat was the best, and this introduced problems in the construction of the complete machine which did not exist in the case of a land machine. The hull panted very considerably on the trolley or in the water, often to the extent of 1in. or $1\frac{1}{2}$ins., and one was faced with the problem of joining a comparatively rigid structure, viz., the main plane to a flexible structure, and to do this in a fairly rigid manner while permitting the hull to retain its flexibility. The problem had not been satisfactorily solved yet. The part of the hull that should be allowed to pant was that which took the greatest shock—the part which came under the main planes. In the usual type of boat that pant was stiffened up with the plane

structure and the wing root stays, and the result was that landing forces caused considerable stresses on the structure itself. Other problems also came in. The pilots' seats should not be attached rigidly; and very great care should be taken with the petrol connections. He had no doubt, however, that the problem would be satisfactorily solved. The question of bulkheads was important. There must be watertight bulkheads and compartments in boats of this type, but whether a bulkhead had been produced that would stand the shock of water coming in had not yet been proved. He did not know whether, if the space behind the bulkhead were filled up with bags containing air, it might be sufficient to make it stand up. The greatest shock the flying-boat industry had had was the death of Major Linton Hope. He was the originator of the circular type of hull and the basket type of construction applied to flying boats, and his pioneer work in these directions was of invaluable service to the industry.

Mr. Gibson Knight said the Author suggested that a committee of naval architects should draw up rules of construction and scantlings. That might ultimately be called for, but the time was hardly ripe for it. Its effect would be to cramp the designer's hand at a time when it should be as free as possible in order that the designing possibilities might be explored in all directions. It was quite advisable that the committee should consist of naval architects, but aircraft designers should be included. With regard to the division of the various types in the Paper, the "Supermarine" was set apart. Why was that done? In general, though perhaps not in points of detail construction, that type fell within the same class as the N.4 and P.5 types of flying boats.

Commander E. S. Land (United States Navy) congratulated Captain Nicolson on the excellence of the Paper; also on his bravery in attacking the problem and attacking the people who had previously attacked it. At first blush his criticism might be considered iconoclastic, but on close analysis it is seen to be clearly constructive and should be welcomed, not only here, but also on the other side and wherever flying-boat construction is under way. With regard to the rules proposal, he (Commander Land) saw no reason why rules should not be laid down. Such rules are applied to boats, yachts and ships; why not to flying boats? He would like to second that suggestion.

The bulkheads are a serious and difficult problem to solve. They add much to the strength of that boat and should be installed. Whether the problem could be solved with the expansion joint, as suggested, without too much weight, he doubted. Putting an expansion joint in a flying boat, where watertight integrity is essential, is a complicated proposition. It might be done with the corrugated or pilaster bulkhead which was sometimes used for expansion purposes.

The Author's notes on the scrieve board they ought to take home and ponder. To do the laying-off properly in the beginning saved time and money and made for efficiency. They had been in this naval architect business since Noah or Jonah, and the mistakes made in this country were also made *ad lib.* on the other side by some people who did not take advantage of the knowledge they had before them. Possibly the pressure of the war was the cause of it. They might take a leaf out of the books of the designers of larger ships. He saw a close analogy between many types of flying boats and submarine and destroyer construction, especially when it came to obtaining proper strength. If one wanted strength and rigidity with resiliency, the latest designs of destroyers should be carefully studied. More strength in the side stringers and deck stringers might have solved some of the difficulties. The Isherwood system, which had been designed here, threw much light on the question of longitudinal versus transverse construction. In America they followed the transverse system until the Isherwood system was tried out, and it was surprising how quickly it was adopted, and how many thousands of tons of shipping were constructed on that principle.

He favoured the longitudinal construction, but most successful types of boat and ship design were compromises. He saw the advantage of the combination of longitudinal with transverse, as in the Isherwood sysem, and there was room for investigation along that line. When he looked at some early flying boats he sometimes wondered whether they had tried to design a spring hat of the latest Paris style or an Old Mother Hubbard shoe house.

In Great Britain and France one found relics decorating golf fields and pastures of some of those early designs. Their ideas of boat construction were not correct at that time, but some of the modern boats indicate that they were getting back to normal and to an appreciation of similarities to the designs of surface craft. The question of size, raised by Commander Cave, was important, because there was a great future for the larger types of boats of this kind.

He regretted that the Author did not say something about all-metal construction. There were a number of types in existence of metal construction, and they were fine looking specimens of work, but how successful they were in trials he could not say. He saw a great future in all-metal construction, both duralumin and strip steel, in which, as far as he was aware, Great Britain led at the present time. He hoped the Author would give his opinion about metal construction when he replied to the discussion.

Mr. Scott-Paine said he had been building circular-constructed flying boats since about 1910, and was beginning to realise how little he knew about it. The difficulties in some instances were extraordinary. It was found many years ago when building light motor-boat hulls with bulkheads that an extraordinary distortion took place in heavy sea-ways, the planking, when breaking, always throwing out forward or abaft bulkheads, while similar hulls without bulkheads seemingly gave no trouble. Some of the racing rules demanded a bulkhead should be fitted, and one of the greatest difficulties was the fact that they had to be made rigidly fast to the sides and the bottom of the hull. In one experience, when running in a heavy sea, some of the planking blew about 6ft. abaft the forward bulkhead; the craft sank and was lost.

It was then tried to get flexible bulkheads, not only on account of the panting of the sides, but of the torsional disturbance of the hull and the coming up or panting of the bottom towards the deck. These were not successful.

The Air Ministry's decision at the recent Martlesham trials that three bulkheads must be fitted to amphibian machines was a great difficulty, it adding much extra weight, the hulls having to be built to stand severe strains in the event of a compartment flooding. This necessary strengthening of hulls was not referred to in the lecture. It might be thought of interest to describe the method of testing trial bulkheads.

An ordinary barrel was taken with one end out, the bulkheads being erected in the middle of the barrel, and by means of a 4in. stand pipe with a 20ft. head, 60 gallons of water were released, which blew the trial bulkheads every time. The difficulty was, however, successfully got over, and stood this pressure on several occasions. The bulkheads weighed about 20lbs. each.

Corrugations suggested by Commander Land would be impossible, as it only gave elasticity in one direction, and would not free the hull from torsional movement.

He was sorry the Lecturer had not said more about the construction and position of steps of hulls, the difficulty being to judge where to place the forward and aft steps to avoid porpoising

Mr. Scott-Paine said he was concerned in the building of a circular hull in 1910. Owing to the available engines, it did not fly. He thought the object

was not to try to make an aeroplane float, but to build a seaworthy hull that would fly.

The CHAIRMAN said he would quote actual facts relevant to Commander Cave's remarks about size. He (Major Low) had launched a theory that there were limits to the possible size of every machine, based on the materials available and on the skill of the designers, and that theory had not been perfectly understood by some critics. For instance, they found Commander Hunsaker, whose very name commanded their respect, saying this theory of geometrical similarity prescribed what would be very bad engineering. Commander Hunsaker said, "Fortunately one need not be discouraged by such theoretical considerations, as one had learnt from past experience that the weight of wings could be kept down nearly in direct proportion to their area. . . . That this result (continued Commander Hunsaker) was quite at variance with the theoretical deductions of several learned writers was illustrated by a table which gave the H.S. flying boat as about three tons, and the N.C. as about 12 tons. The theory of similarity showed as a first approximation that if one went from three tons to 12 tons, which was four times, the obvious way to do it was to cut one's factor of safety in half. That would give half the constructional coefficient, and according to the theory of geometrical similarity, which was admittedly a first approximation, the factor of safety was halved and the total weight multiplied by four." Having produced this table to kill the theorist and prove there was no limit, Commander Hunsaker (on page 732 of the "Journal of the Franklin Institute") said: "A point of interest not brought out in the table is that the structural factor of safety has fallen from six in the H.S. type weighing three tons to three in the N.C. type weighing 12 tons." He had in fact started out to curse the learned theorists, but by his table he confirmed his (Major Low's) firm belief that there were definite and close limits to the size of flying boats. He would be glad, without any consulting fee, to consult with any technical member of any designing firm not only in the application of this first approximation theory of geometrical similarity, but in the further approximation made possible by finer design on larger machines, and he thought it would save a great deal of money if it prevented people from launching out into 20 and 40 tonners and transatlantic liners which were going to carry hundreds of people. He believed he would save the industry and capitalists many hundreds of thousands of pounds if they consulted him first on this theory of the limitation of sizes. If only the hull had to be considered there would be no apparent limit in sight. It was the increasing weight of the wings which controlled the size.

The Chairman went on to approve warmly of the principle of handing over specialist parts of design to specialists, and in particular of consulting the yacht builder and naval architect when it came to the construction of hulls.

On his own behalf he thanked the lecturer warmly for one of the most satisfying papers he had listened to before this Society.

REPLY.

It will be noted that every speaker has dealt with the topic of bulkheads; this interest proves the truth of what I had stated—that a committee should be formed to look into the very important question of W.T. sub-division and methods of construction. I am convinced that if two or three naval architects are on such a committee, the bulkheads that are desirable will be obtained. It will be noted that shipbuilders realise the importance of this question, as at a recent meeting of the Institution of Naval Architects two papers were read on the same subject for larger boats. Shipbuilders have now got the effective bulkheads they require, as they have the experience of over 100 years of boat building

to go by, and yet we see aircraft builders starting off in a new direction when most of their difficulties have been solved by naval architects many years ago.

Wing-Commander Cave-Browne-Cave would like to have heard more on the subject of design, but I am sure he realises that it is not possible to treat both subjects at length in one paper. I might refer him to a paper I read before the Institution of Engineers and Shipbuilders in Scotland, in April, 1919, where he will find the design of flying boats dealt with more fully.

He also asks if the bulkheads I advocate would stand the inrush of water if the boat was going at a great speed on the surface of the water? There are very few cases when boats' bulkheads would be called upon to withstand such a pressure, but if the collision bulkhead was built in the form of a $<$ it should stand up as well as the original bow.

Sand loading tests have not been carried out to any extent on flying boats.

The late Major Linton Hope gave an example of a sand loading test on the A.D. boat in his paper before this Society, and later the N.4 Atlanta hull was tested for flexibility and bending, but the N.4 hull built on the longitudinal system has not yet been tested, so no comparison of the various types of hulls has yet been made, as the "A.D." and "Atlanta" are built on similar lines. However, sand loading tests are of very little value in determining if a boat's hull will give the required amount of flexibility and be seaworthy to stand the abuse they get by the sea.

Commander Cave-Browne-Cave states that the man who departs from accepted naval architects' practice is going to have difficulty in making his case; this is exactly what I have been trying to point out all along, but it does not seem to appeal to many aircraft designers and builders.

In yacht and boat building the test of weather and trials have proved to shipbuilders the types of construction which are best, but this depends of course on the duty and function the boat has to perform.

Naval architects design and build a boat in accordance with the kind of cargo she has to carry, or the climatic conditions under which she is to operate, or any other special trade which she may be called upon to run. The same applies to flying boat hulls. If a naval architect is told the duties the boat has to perform it will then be easy for him to decide on what type of construction should be adopted. With reference to the question on size of hulls I do not think this will trouble the shipbuilders for very many years to come, as we have had so much experience in large boat building. I have designed and built boats weighing as many tons as the largest present flying boats weigh in lbs.

If flying boats increase above, say, 80ft. in length, or over 30,000lbs. in weight, then metal construction could be profitably used.

Mr. Manning mentions panting of hulls, and this, as he states, is one of the vital points to be noted when designing a hull. The position and amount of panting cannot be calculated, therefore it is only by years of experience and by hundreds of tests that this factor can be obtained. As this has been the work of naval architects in the past I cannot now understand why they should not be consulted on the subject.

I am glad to note that Commander E. S. Land, of the U.S. Navy, seconds my suggestion that flying boats should be built under classification rules.

Commander Land, being a practical man, knows the importance of the scrieve board, and I hope his advice will be taken.

It may be interesting to the designers in this country to note that throughout Commander Land's remarks it can be seen that the Americans understand the

close analogy between flying boat construction and other types of shipbuilding and that on the other side naval architects are engaged on flying boats.

With reference to metal construction, as I have already stated, it certainly should be used when we come to the dimensions named in my reply to Commander Cave-Browne-Cave.

I have had a good deal of experience with steel boats and found that the material was not very suitable for light high-powered boats under 50ft. in length.

The chief disadvantages were the difficulty of obtaining a fair surface, which is of great importance in this type of boat, and secondly, the difficulty of making satisfactory joints in the material which was employed; but as the boats increased in size the difficulties disappeared and the metal construction became easier than wood.

With reference to Mr. Scott-Paine's remarks on the position of the steps, this is a question of design which can easily be determined by experiment with models in tank tests.

Mr. Gibson Knight does not seem to realise the assistance that would be rendered by a committee to aircraft designers if scantling rules were drawn up. For instance, anyone knowing Lloyd's rules for the construction of power boats appreciates how valuable the tables and information given are to designers and builders. Instead of cramping the designers' hands it would provide them with very valuable data and obviate masses of calculations. Mr. Knight is quite correct in stating the supermarine type of construction is practically the same as the P.5 and N.4. All interested in flying boat construction know that the general features of the supermarine type of hull are similar to the above-mentioned types, so it was unnecessary for me to refer to them in detail. I also had dealt with the P.5 and N.4 at greater length in previous papers.

From experience I know exactly how long the boat builders took to do the diagonal planking and the time taken to cover the same area with the fore and aft planking, and have shown comparative figures of the times taken and also the wages paid. Again, anyone who has had experience in laying out fore and aft planking knows that the fairing and tapering each plank is a big job, while the diagonal planking is more or less parallel.

I agree with Captain Sayers that great credit is due to the men who designed and built the first "F" boats, but he is wrong in stating that they received no encouragement from naval architects. I know that the late Major Linton Hope and Captain Shepherd put many suggestions forward. Again, I personally interviewed the designers and builders and pointed out many of the details that were entirely opposed to the usual naval architects' or boat builders' practice, and suggested where the badly designed parts would fail. For instance, the stopping of timbers at the keel, the small connection of bottom planking to keel, discontinuity of strength members, the butting of double planks together, the U boat method of connecting keel to keelson, etc., etc., all of which is never seen in power boats, proved, as I had stated, to be weak and all had to be strengthened up with continuous timbers, etc.

When Major Hope read his paper before this Society he stated that his designs were not as he would have turned out if he had been allowed a free hand; so here again Captain Sayers will see that naval architects have not had the chance which I consider is due to them.

Major A. R. Low's remarks are very interesting and I agree with him that if only the hull had to be considered there would be no apparent limit in sight.

Many theoretical engineers state that 10,000lb. is the limit to the size of flying boats, because the law of dimensions lays down that areas increase as the

square, and weights as the cube, of the dimensions, but this theory has been upset as larger boats have now been flying. Some reasons for the apparent theoretical discrepancy is that the larger the flying boat the more detailed can be the design work and the material used in a more efficient manner; also the factor of strength can be cut down as one does not want to loop or do stunts with a large passenger flying boat.

The question of anti-fouling raised by Colonel the Master of Sempill is one of the most important subjects to be dealt with on flying boat hulls. The bronze powder he mentions has not to my knowledge been used on racing yachts. As the bottoms of these boats are scrubbed every two or three weeks, no advantage is gained by copper sheathing or bronze powdering, but for cruising yachts the powder applied as suggested by Colonel Sempill would prove fairly satisfactory. Many hundreds of experiments have been tried to produce a perfect anti-fouling paint, but this has not yet been invented. Many compositions are in the market at present, but all that can be said of them is that they are more or less successful in retarding or delaying fouling. The success of an anti-fouling paint depends very largely on the method of applying it, and every maker gives instructions with his composition as to how it should be used. One of the important points to be noted is that the composition should be kept well stirred whilst being used as the ingredients are heavy and soon settle to the bottom.

Again, the success of the composition depends greatly on the boat's movements after coating, the time she lies in harbour, the particular seas navigated (whether warm, tropical, or cool), the season of the year, and other matters. A composition may be found quite good for a boat in a certain district, but the same one might be quite useless in another boat differently engaged. It might wash off too quickly, or too slowly, or it might be insufficiently poisonous, or its anti-fouling qualities might not be fully developed at the right time. I think the above will prove to Colonel Sempill that the wrong kind of composition was used on the boats in the south of Italy. It is on these lines that I should recommend research. As it is an established fact that all climates and districts require a different composition, pieces of timber or floats should be tested with various compositions, and types of marine growth noted for each district, and then these particular growths of marine life can be more successfully dealt with. The whole experiment must be carried out where the boat is to be engaged, and by doing this fairly good results should be obtained. Colonel Sempill states that boats moored out for less than a fortnight become very dirty; this should not have been the case and appears to show that the wrong kind of composition must have been used, as when a boat is lying in harbour the contiguous layer of still water may be rendered so highly poisonous as to turn off or destroy any germs essaying to attach themselves, but when at sea, any poison that exudes from the paint is so diluted by the limitless volume of pure water passing over the surface that its deleterious effect becomes inappreciable. The general procedure followed at present is that tests may be made on, say, the river Tyne and a fairly successful paint found for the East Coast, but as the marine life found there is different from that, say, of the south of Italy, the same composition would probably be useless, so here Colonel Sempill has a very wide field for research.

I must thank Mr. Penny for his appreciation of my paper, and as is to be expected, as he is a naval architect, we have many views in common. Had I included a discourse on superstructure and engine installation in the paper, I am afraid my audience would have expressed the opinion that the paper was too lengthy.

The subject of flying boats, as a whole, embraces so many different phases and questions that it is impossible to deal with all in one paper, so there exists a splendid opportunity for other papers on such details as I intentionally omitted. Doubtless Mr. Penny, being a member, will favour the Society with his views

in the form of a paper. With reference to his remarks on resistance or drag set up by the superstructure, I heartily agree.

I do not think I have created a false impression with reference to the supermarine boats, as my remarks on circular hull construction applied to all boats of this type; I took the original A.D. as a basis for discussion and did not discuss the A.D. hull to the exclusion of the N.4, P.5, etc.

Mr. Penny is quite correct in stating that the present methods of constructing the A.D., P.5 and N.4 flying boats is not new, and has been common boat building practice for years, but I must take exception to the inclusion of the bottoms of the F.5, as I am sure that if Mr. Penny more closely examines the construction of the F.5 bottom he will agree that it cannot be classed as boat building practice.

Referring to Mr. Penny's remarks on my critics, if he will look through my replies to Wing-Commander Cave, Mr. Gibson Knight and Colonel the Master of Sempill, he will find that I have agreed with him.

THE EFFECT OF ATMOSPHERIC PRESSURE AND TEMPERATURE UPON THE PERFORMANCE OF A PETROL ENGINE.

THE USE OF SUPERCOMPRESSION IN AERO ENGINES.

BY E. G. RITCHIE, D.SC., A.M.INST.C.E., A.M.I.MECH.E., OF THE RESEARCH ASSOCIATION OF BRITISH MOTOR AND ALLIED MANUFACTURERS.

The efficiency of all internal combustion engines is influenced to a large degree by the density of the charge prior to ignition. In the stationary engine operating at normal ground density, the variation in compression pressure throughout the range of working conditions is so small as to have no appreciable effect upon engine performance. In the aero engine, however, the conditions obtaining in flight are such as to produce wide variation in the suction pressure and therefore in the compression pressure due to changes in atmospheric density.

Table 1 has been prepared to show the variation in air pressure, temperature and density with height, the figures given representing the mean conditions obtaining in the south of England.

TABLE 1.

Altitude in feet ...	0	5,000	10,000	15,000	20,000	25,000
Pressure in lbs. sq. in.	14.65	12.35	10.15	8.25	6.70	5.45
Temperature °C ...	+11.0	+4.0	—4.5	—15.0	—26.0	—37.5
Density in lbs. per cu. ft.	.0785	.0676	.0570	.0486	.0415	.0346

From the above table it will be realised that the wide range of conditions under which the aero engine is required to operate places this form of prime mover in a class altogether by itself.

In what follows, it is proposed to discuss the effect of change in atmospheric pressure and temperature upon the performance of the normal aero engine, and to consider the influence of compression ratio upon the efficiency of an engine when operating under the conditions obtaining at high altitude.

The effect of air density upon engine performance is not capable of presentation in simple form, as different engines are found to react differently towards changes of pressure and temperature. In what follows the effect of these two variables is treated separately.

(1.) Effect of Air Pressure on the Performance of the Normal Aero Engine.

The weight of air entering the cylinder of an internal combustion engine is proportional to the density of the charge, and if the temperature remains constant, is therefore proportional to the pressure, on the assumption that all other variables such as engine adjustment, speed, etc., remain constant. The theoretical mean pressure may be readily shown to be given by

$$\eta(P_3 - P_2)/(\gamma - 1)\,(r - 1).$$

Where $(P_3 - P_2)$ is the theoretical rise in pressure following ignition, η is

the theoretical thermal efficiency, γ is the adiabatic exponent for air, and r is the compression ratio.

Since η is dependent only upon the temperature cycle, the theoretical mean pressure is seen to be directly proportional to $(P_3 - P_2)$ and therefore directly proportional to the initial pressure, if the initial temperature and the compression ratio remain constant. It would thus appear that the indicated mean effective pressure and, therefore, the i.h.p. of an engine, is directly proportional to density, if the air temperature remains constant.

No data as to variation in i.h.p. with density is available, but deductions made from observations on the variation of b.h.p. with density would appear to indicate that the above relationship substantially holds, down to a density corresponding to approximately 60 per cent. of ground density.

Observations made on several aero engines under artificial altitude conditions, with a view to investigating the variation in b.h.p. with air density, are shown in Fig. 1. In these tests ground temperature conditions were maintained constant throughout, the density being reduced by reducing the inlet and exhaust pressures.

The various engines tested were as follows :—

(1) 12-cylinder Vee aluminium cylinder air-cooled engine, bore 100 mm., stroke 140 mm., compression ratio 4.7 : 1, speed 1,600 r.p.m.*

(2) 12-cylinder Vee cast-iron cylinder air-cooled engine, bore 100 mm., stroke 140 mm., compression ratio 4.4 : 1, speed 1,400 r.p.m.†

(3) 8-cylinder Hispano Suiza water-cooled engine, bore 120 mm., stroke 130 mm., compression ratio 4.6 : 1, speed 1,550 r.p.m.‡

Each engine was run under normal full throttle conditions at the speeds indicated above, the petrol flow being adjusted under each pressure condition to give maximum load on the lowest possible fuel consumption.

In Fig. 1, brake horse-power and petrol consumption per hour, expressed as a percentage of ground power and consumption, are plotted against air pressure expressed as a percentage of ground pressure.

(2.) Brake Horse-Power and Air Pressure.

The plotted results indicate that in each engine the b.h.p. falls off at a sensibly constant rate down to a pressure corresponding to approximately 60 per cent. of ground pressure. The rate of decrease is evidently dependent upon compression ratio, increasing with decrease in compression ratio.

Engines (1) and (2) were tested under identical conditions and under the same authority; the results may therefore be taken as directly comparable. From the plotted results it will be seen that while in the former engine, the b.h.p. is directly proportional to air pressure, in the latter, the b.h.p. falls off more rapidly than air pressure, the difference amounting to nearly one per cent. for each 10 per cent. drop in air pressure. With air pressures lower than about 60 per cent. of ground pressure the rate of decrease of b.h.p. increases rapidly, the increase being approximately the same in each case.

Tests carried out on engine No. 3, under the authority of the U.S. Bureau of Standards, show that the effect of reduction in atmospheric density increases with increase in engine speed as indicated in Table 2.

* Observations by Professor A. H. Gibson, D.Sc., M.Inst.C.E., M.I.Mech.E., at the Royal Aircraft Establishment.

† Observations made by the Author at the Royal Aircraft Establishment.

‡ U.S.A. Bureau of Standards.

TABLE 2.

Air Pressure. Ins. of Mercury.	Air Pressure. Relative.	Engine R.P.M. 1,300	Engine R.P.M. 1,700	Engine R.P.M. 2,100
29.9	100.0	100.0	100.0	100.0
24.4	81.6	81.8	82.0	81.4
19.7	65.9	65.7	65.2	64.3
14.8	49.5	48.9	48.4	47.4
10.1	33.8	33.6	32.1	30.4

(Engine R.P.M. columns: Relative b.h.p.)

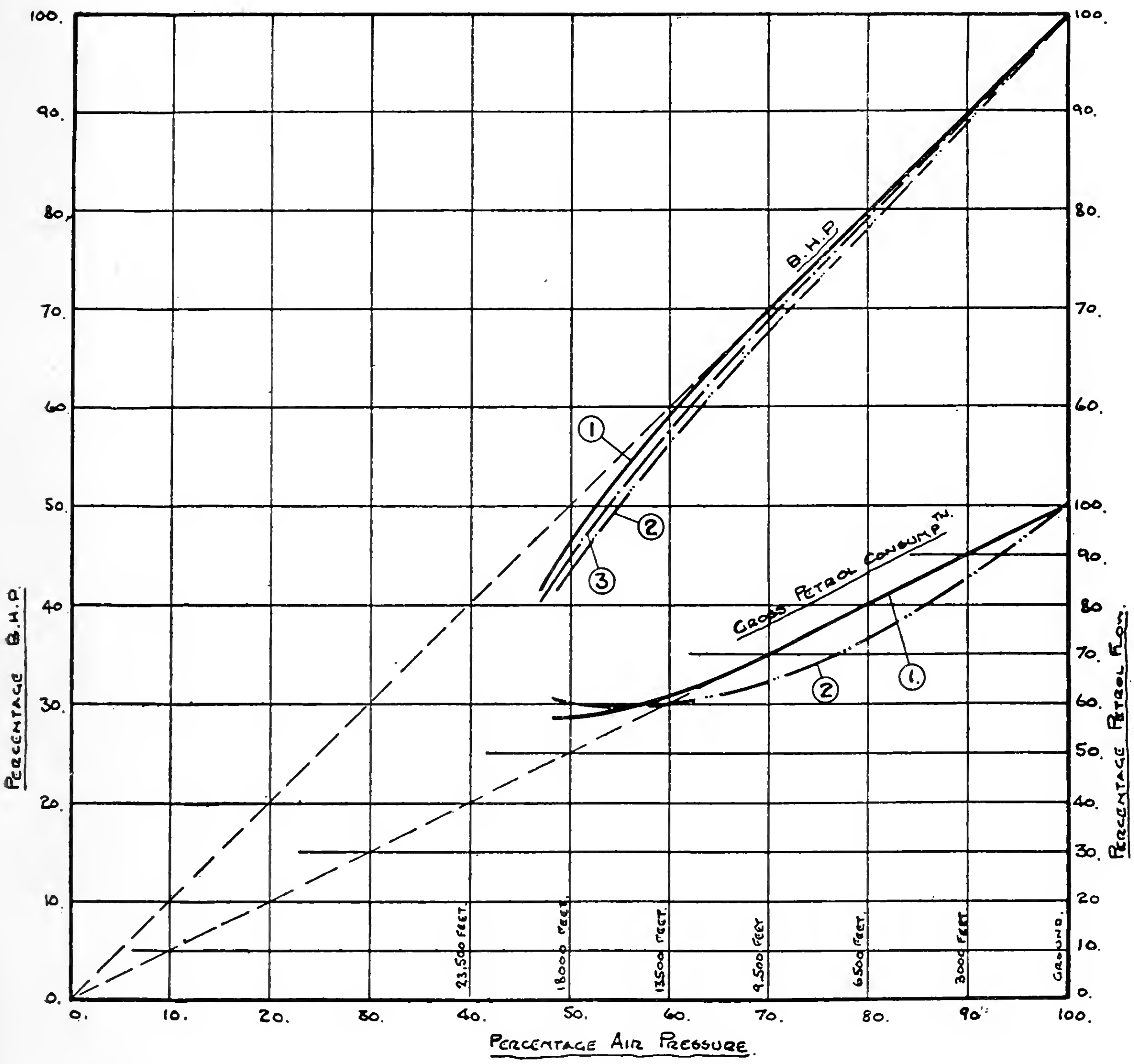


Fig. 1.

(3.) Petrol Consumption and Air Pressure.

The observations plotted in Fig. 1 show that the gross fuel consumption per hour is nearly proportional to air pressure down to a density corresponding to between 60 per cent. and 70 per cent. of ground density. With densities lower than this, the consumption decreases less rapidly than air pressure. The con-

sumptions in lbs. per b.h.p. per hour corresponding to the plotted results for engines 1 and 2 are as follows :—

TABLE 3.

	Relative Air Pressure.					
Engine.	1.000	.900	.800	.700	.600	.500
(1)	.533	.533	.533	.541	.581	.687
(2)	.563	.563	.563	.578	.651	.793

From the above it will be seen that while the petrol consumption per b.h.p. per hour is sensibly constant in both tests down to a pressure of 70 per cent. to 80 per cent. of ground pressure, beyond this point, the consumption increases rapidly with diminishing density. The petrol flow in the case of the Hispano Suiza engine tests was not observed. The consumption on this engine under normal ground conditions is however somewhat higher than on No. 1 engine, and is lower than No. 2 engine. In the tests on engines 1 and 2, arrangements were made for controlling the petrol flow, and under each test condition, this was adjusted to give minimum petrol consumption consistent with the maintenance of full load. Any reduction in the petrol consumption below the figures given resulted in a drop in power over the whole range of pressures tested. It would therefore appear that the rate at which the b.h.p. decreases with diminishing density is greater in an engine having a low thermal efficiency. In this regard, it is noteworthy that the power of a rotary engine falls off much more rapidly with height than does a stationary engine of either the radial or line type. In the normal rotary engine, the induction system is recognised to be faulty, and conditions are such as to militate against the development of high thermal efficiency. The influence of air density on thermal efficiency is further referred to in para. 12.

(4.) Effect of Air Temperature on Engine Performance.

Since the power output of a petrol engine is dependent upon the weight of charge drawn into the cylinder, the effect of an increase in air temperature—other conditions remaining constant—may therefore be expected to reduce the power output, and a decrease in air temperature the reverse. The effect of air temperature variation upon power is not however a primary one, the quantitative effect depending upon carburettor and induction pipe design, mixture strength, etc. During its passage from the carburettor to the cylinder, the petrol is partially vaporised, absorption of the latent heat necessary for this process causing a drop in temperature as between the inlet air and the charge in the induction pipe. The nett result of this is, that the density of the charge is effected by change in air temperature to a lesser degree than that of the intake air. Increase in air temperature not only causes increased atomisation at the jet, due to decrease in the viscosity and surface tension of the petrol, but also gives rise to greater evaporation in the induction pipe. Even in the simple unheated induction system, conditions are thus seen to be complex. In the multi-cylinder engine, fitted with a heated induction pipe, further complications arise. Preheating of the charge, while reducing the charge density, improves the distribution. Reduction of the charge weight tends to reduce the power output, while better distribution tends to increase it.

As showing the effect of change in inlet air temperature on the performance of a single-cylinder water-cooled petrol engine, results obtained in a series of tests carried out by the author are discussed below.*

The tests were conducted on a single cylinder taken from the 300 h.p. Fiat Aero Engine, the bore and stroke of which are 160 mm. and 180 mm. respectively.

* Advisory Committee for Aeronautics, I.C.E. Report 281.

The observations were made with a compression ratio of 6.0 : 1. Arrangements were made whereby the inlet and exhaust pressure could be regulated, and the inlet air temperature varied between — 10° C. and + 50° C. The carburettor and induction pipe were unjacketted. The tests were carried out at a constant engine speed of 1,550 r.p.m., observations being made over a range of absolute air pressures varying from 10 to 19ins. of mercury. Under each condition as to pressure and temperature, the petrol flow was adjusted to give maximum load on the lowest possible consumption. Induction pipe temperatures were measured by means of a shrouded platinum-iridium thermocouple. The results obtained are shown in Fig. 2, and are discussed below.

(5.) Air Temperature and Charge Temperature.

The induction pipe temperature observations indicate that the temperature difference between the inlet air and the charge in the induction pipe is sensibly independent of air pressure, but increases with increase in intake air temperature. The mean results obtained in each series were as follows :—

TABLE 4.

Intake air temperature. °C.	—8.8	+13.0	+45.0
Temperature charge in induction pipe. °C	—20.6	—11.7	+6.3
Temperature difference between intake air and charge. °C.	11.8	24.7	38.7

The relationship between the inlet air temperature and the induction pipe temperature is substantially represented by

$$T = .515\theta - 16.9.$$

Where T is the induction pipe temperature in °C. and θ is the intake air temperature in °C. the relationship between induction pipe temperature and intake air temperature depends essentially upon the mixture strength, the degree of atomisation at the jet, and the subsequent condition of the mixture in the induction pipe. Tests carried out by Dr. A. H. Gibson on a single-cylinder air-cooled engine gave the following relationships :—

$T = \theta^{1.5}/13$ for normal mixtures (.45/.55lbs./b.p.h./hr.)
$T = \theta/2$ for rich mixtures (.67/.81lbs./b.h.p./hr.)

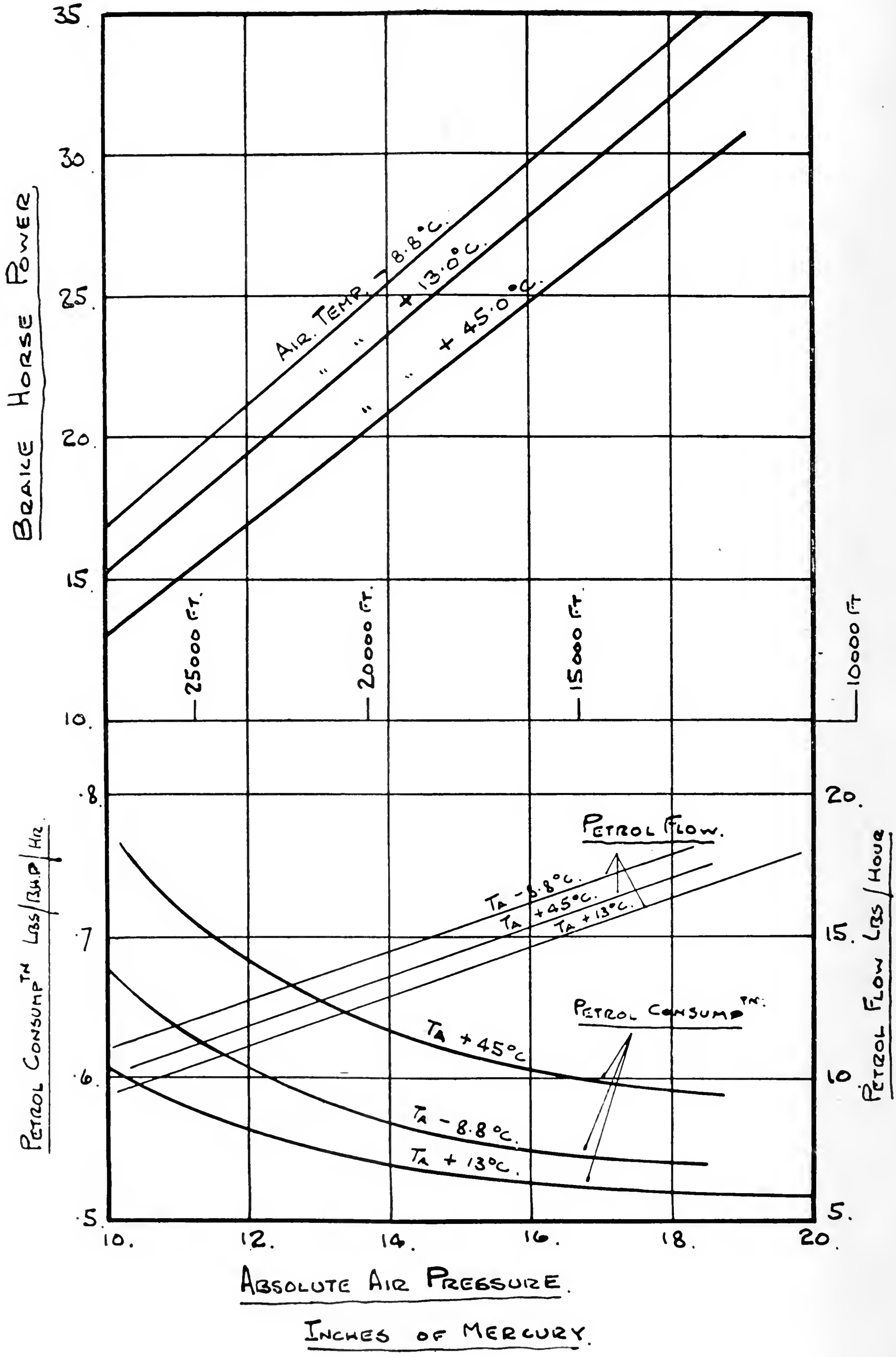
while the relationships found to hold in the case of engines 1 and 2 of para. 2 were as follows :—

Engine 1. $T = .3\theta - 4.$
Engine 2. $T = .25\theta.$

It would thus appear that the drop in temperature across the carburettor varies widely in different engines, and is in fact a function of so many variables, that no relationship having a general application is possible of formulation. With a mixture strength of 14lbs. of air per lb. of petrol, the temperature drop accompanying complete vaporisation of the fuel may be shown to be approximately 22° C. In the normal induction system vaporisation is incomplete, and with a mixture strength of the above composition the temperature drop is less than that given. With mixtures richer that 14 to 1, the temperature drop is proportionately greater, due to the relatively greater evaporation of the lower boiling fractions.

(6.) Air Temperature and Power Output.

From Fig. 2 it will be seen that the b.h.p. increases with a reduction in air temperature over the range of temperature tested. The temperature effect is dependent upon air pressure, diminishing with increase of pressure. The per-



Brake Horse Power
35.
30.
25.
20.
15.
10.
Air. Temp. − 8.8°C.
" " + 13.0°C.
" " + 45.0°C.
25000 F.T.
20000 F.T.
15000 F.T.
10000 F.T.
Petrol Consumpᵀᴺ Lbs/B.H.P/Hr.
·8.
·7
·6.
·5.
20.
15.
10.
5.
Petrol Flow Lbs/Hour
Petrol Flow.
Tᴀ − 8.8°C.
Tᴀ + 45°C.
Tᴀ + 13°C.
Petrol Consumpᵀᴺ.
Tᴀ + 45°C
Tᴀ − 8.8°C.
Tᴀ + 13°C.
10.
12.
14.
16.
18.
20.
Absolute Air Pressure.
Inches of Mercury.

Fig. 2.

centage increase or decrease in b.h.p. with temperatures below or above 0° C. has been calculated over a range of absolute air pressures from 10 to 18ins. of mercury. Taking the b.h.p. developed with an air temperature of 0° C. as a basis of comparison, the b.h.p. developed with a temperature θ° C. is given by $P_0(1 \pm \theta/K)$.

Where P_0 is the b.h.p. developed at 0° C., the term θ/K being added or subtracted according as θ is below or above zero.

The value of K increases with a decrease in absolute air pressure as shown below.

TABLE 5.

Absolute air pressure in ins. of Mercury ...	10.	12.	14.	16.	18.	29.9
Value of K	187.	243.	290.	339.	386.	between 500 and 600

The value of K at a pressure of 29.9ins. has been obtained by extrapolation.

Tests carried out by Dr. A. H. Gibson on an aluminium air-cooled single-cylinder engine under ground pressure conditions, showed the necessary power correction for normal mixtures to be $(1 \pm \theta^{1.5}/3{,}500)$, and for rich mixtures $(1 \pm \theta/546)$. The latter is in fair agreement with the extrapolated value given in Table 5. From the above it would appear that the value of K depends not only upon the air temperature, but also upon the mixture strength, decreasing with increasing richness. The decrease in K with diminution in air pressure observed in the series of tests under discussion, is partly due to this cause, the results obtained showing an increase in consumption with diminishing air pressure as indicated in Fig. 2. The value of K will also vary with the type of carburettor employed, depending upon the degree of mechanical atomisation at the jet, and upon the design of the induction pipe.*

(7.) Induction Pipe Temperature and Power Output.

As indicated in para. 6, the effect of variation in air temperature upon the power output of an engine differs in different engines, and for this reason any relationship connecting the two is unsatisfactory. Such data as is available does, however, point to a definite relationship between the power developed and the temperature of the charge in the induction pipe.

From the tests referred to in para. 4 the following figures have been deduced :—

TABLE 6.

Mean Inlet Air Temp. ° C.	Absolute Air Pressure in inches of Mercury. 10.	12.	14.	16.	18.	
—8.8	4120.	5330.	6470.	7420.	8330.	Values of b.h.p. × abs. temp. of charge in induction pipe.
+ 13.0	4020.	5200.	6350.	7310.	8330.	
+ 45.0	3500.	4700.	5760.	6850.	8030.	

From the above it will be seen that the product of the b.h.p. and the absolute charge temperature is sensibly constant for air temperatures of — 8.8° and + 13.0° C., under similar air pressure conditions, the error made in assuming inverse proportionality between absolute charge temperature and power output nowhere exceeding one per cent. The agreement is not so close in the tests carried out with an air temperature of + 45° C., particularly with the lower air

* For further data on the influence of induction pipe design upon power variation with temperature, the reader is referred to "Aero Engine Efficiencies," Professor A. H. Gibson, D.Sc., M.Inst.C.E., M.I.Mech.E., Transactions of the Royal Aeronautical Society, vol. 3.

pressures. It is to be observed, however, that with this temperature the petrol consumption was excessive, and the conditions as to temperature were such as are not likely to occur under actual conditions of flight.

Experiments carried out by Dr. A. H. Gibson on a single-cylinder air-cooled engine showed that at constant air temperature, the effect of engine-speed, and therefore of gas-speed, on induction pipe temperature was relatively small, while a change in air temperature over a range from $+2°$ C. to $+82°$ C. had very little effect upon cylinder temperature, and therefore upon heat loss to the walls. In this respect, increase in air temperature as effecting increase in wall temperature appears to be counterbalanced by the reduction in power output as effecting reduction in wall temperature.

The evidence given above, together with much confirmatory evidence, would appear to establish the fact that over a wide range of pressure and temperature, and with normal mixture strengths, the power output of a petrol engine is inversely proportional to the absolute temperature of the charge in the induction pipe.

(8.) Effect of Air Temperature on Petrol Consumption.

Experience shows that the majority of petrol engines develop maximum power on a mixture strength considerably richer than that corresponding to maximum economy, the excess of petrol being mainly required to prevent the charge rising to its spontaneous ignition temperature. Increase in air temperature results in higher compression temperature, and in consequence, under maximum load minimum consumption conditions, a greater excess of petrol is required if spontaneous ignition of the fuel is to be prevented. Conversely, a limited reduction in air temperature may be expected to effect a reduction in fuel consumption. Apart from the conditions obtaining in the cylinder, however, the air temperature has a material influence upon the condition of the charge in the induction pipe, and therefore upon the fuel consumption.

The viscosity of the fuel increases, while the vapour pressure decreases, with reduction in temperature, both of which factors adversely affect the condition of the charge. In practice, decrease in air temperature may be expected to have a beneficial effect upon fuel consumption down to a point at which non-homogeneity of the mixture begins to interfere with charge distribution. Beyond this point, reduction in air temperature will obviously have an adverse effect upon fuel consumption. From the nature of the case, the effect of temperature upon fuel consumption will differ in different engines. In the multi-cylinder engine, pre-heating of the charge is found to be essential under the low temperature conditions obtaining at high altitude, due to the adverse effect of low temperature on charge distribution. Under ground temperature conditions, with a well-designed induction system, jacketing has invariably the effect of reducing the power output of the engine and of lowering its thermal efficiency.

The test results plotted in Fig. 2 show that whereas the b.h.p. increases with decrease in air temperature, over the range of temperatures tested, minimum petrol consumption per b.h.p. per hour was obtained with a mean temperature of $+13°$ C. The results obtained indicate that in this engine an air temperature of approximately $0°$ C. corresponds to conditions of maximum efficiency. Temperatures lower than this have evidently a detrimental effect upon the condition of the charge. Using the results obtained with an air temperature of $13°$ C. as a basis of comparison, it will be seen that with an air temperature of $45°$ C. the consumption per b.h.p. per hour is approximately 14 per cent. greater with an absolute air pressure of 18 inches of mercury, the difference increasing to 21 per cent. with an air pressure of 12 inches of mercury. The corresponding increase with an air temperature of $-8.8°$ C. is approximately 4 per cent. with the higher pressure and 6 per cent. with the lower pressure.

(9.) Effect of Compression Ratio on the Performance of an Aero Engine Operating under Reduced Density Conditions.

The theoretical efficiency and theoretical mean pressure of an internal combustion engine increase indefinitely with increase in the ratio of compression. In a petrol engine, operating on full throttle at a given air density, the extent to which the compression may be raised depends upon a number of factors, of which the spontaneous ignition temperature of the fuel is the most important. For normal combustion this temperature must not be exceeded during the compression stroke, and in the average well designed engine operating on the ground it is found that a compression ratio of from 5.0 to 5.3 : 1 is the maximum permissible, consistent with the maintenance of normal operation on full throttle.

Since the temperature at the end of compression is theoretically dependent only upon the ratio of compression and the initial temperature, the compression temperature would appear to remain constant with diminishing density if the initial temperature remains constant. Under engine conditions, however, the compression temperature is dependent upon cylinder temperature, and this decreases with decrease in the weight of charge dealt with per cycle and therefore with decrease in atmospheric density.

In the case of an aero engine operating under reduced density conditions at altitude, the initial pressure and temperature, and hence the compression pressure and temperature are considerably lower than under ground conditions, and in consequence, in the normal aero engine adjusted to give the maximum permissible compression on the ground, the temperature at the end of compression is well below the spontaneous ignition temperature of the fuel. In effect, an engine which is adjusted to give the maximum possible efficiency on full throttle on the ground is essentially operating under conditions of low efficiency at altitude.

The following tests were carried out by the author, with a view to investigating the effect of high compression upon the performance of an aero engine under reduced density conditions.

The investigation was conducted in the altitude test house at the Royal Aircraft Establishment.* A single cylinder from the 300 h.p. Fiat aero engine was employed, and arrangements were made whereby the inlet and exhaust pressure could be reduced to that corresponding to any altitude up to approximately 30,000 feet. The temperature of the intake air was maintained sensibly constant throughout the tests, varying from 13° C. to 17° C. In each test the quantity of heat given to the jackets and the heat loss in the exhaust were determined, an exhaust gas calorimeter being employed for the latter purpose. The carburettor was fitted with a variable jet, and under each test condition the petrol flow was adjusted to maintain maximum load on the lowest possible petrol consumption. The spark advance was maintained at 35° C. except where mentioned. Precautions were taken to maintain constant oil temperature throughout the series, and correction was made for mechanical losses in the test bed not directly attributable to the cylinder. These include the mechanical losses in the bed apart from crankshaft and piston line losses, such as centrifugal pump drive, etc. The b.h.p. absorbed in such losses under the conditions of the test was separately determined by means of an electric dynamometer.

Tests were made with compression ratios of 4.0, 4.8, 6.0 and 7.6 : 1. With the first three ratios the standard piston was employed, the clearance volume being adjusted by shims under the cylinder flange. The highest compression was obtained by the use of a special piston similar in general design to the standard piston, but having the crown chamfered off at the edge to prevent over-running of the sparking plug. The fuel employed was Shell Aviation Spirit having a

* Advisory Committee for Aeronautics, I.C.E. Report, 281.

density of .715 and a nett calorific value of 18,600 B.Th. U.'s per lb. The tests were conducted at a speed of 1,550 r.p.m.

(10.) Variation in B.H.P. and Petrol Consumption with Compression Ratio.

The variation in b.h.p. with air pressure for the various compression ratios is shown graphically in Fig. 3, all of the observations plotted being obtained on

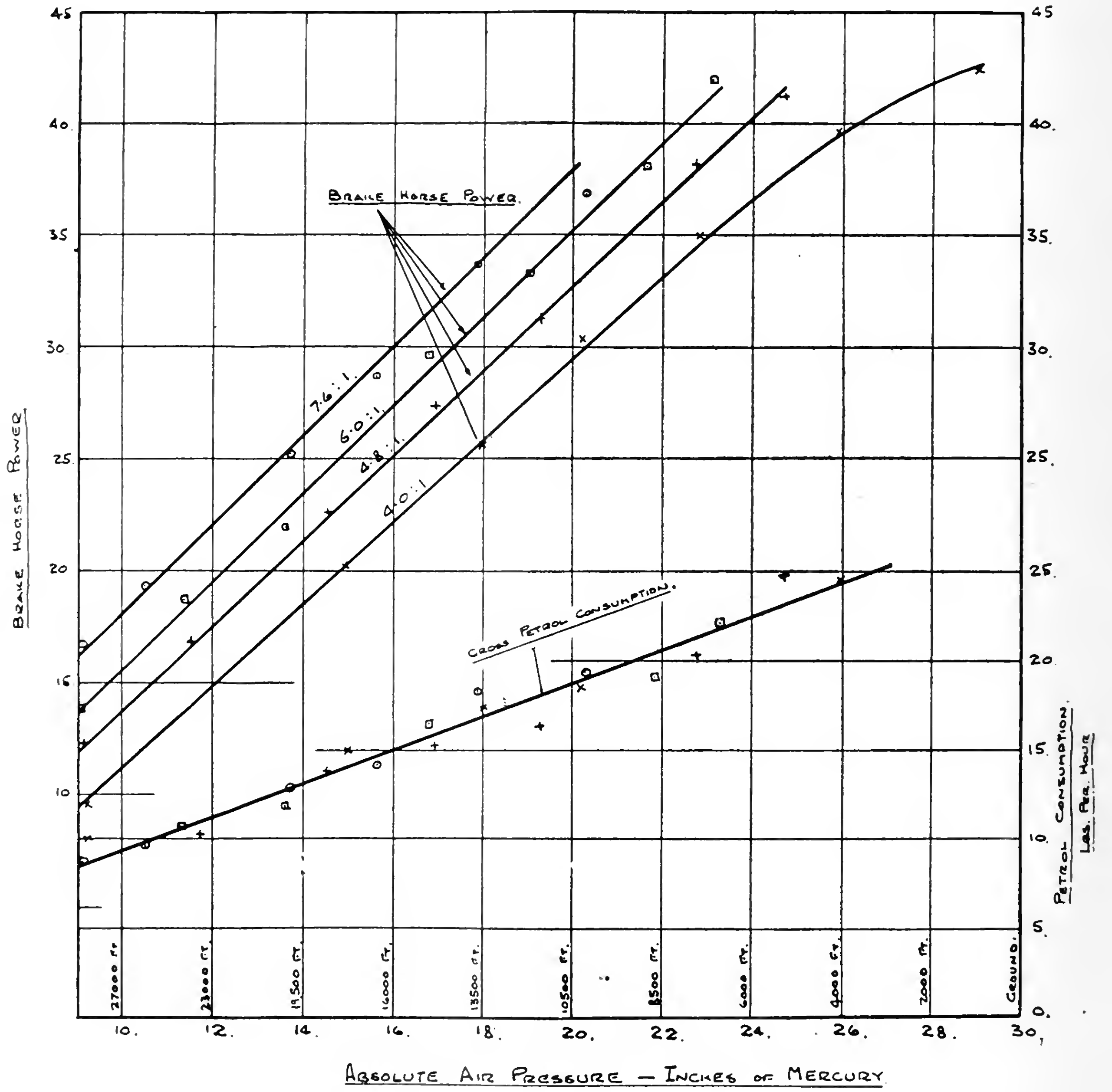


Fig. 3

full throttle. The variation in gross petrol flow is also shown in Fig. 3, while petrol consumptions per b.h.p. per hour are plotted in Fig. 4.

The maximum air pressure at which the engine could be run on full throttle without detonation with the highest compression ratio tested, was found to be approximately 20 inches of mercury. Using the b.h.p. developed with each ratio at this air pressure as a basis of comparison, the percentage drop in power and petrol flow with diminishing density have been calculated and are shown plotted against percentage air pressure in Fig. 5.

(*a*) **Brake Horse-Power.**

An examination of Fig. 3 shows that under reduced density conditions substantial increase in power is obtainable by the use of higher compressions than are normally employed in aero engines. The normal compression ratio of the 300 Fiat engine is 4.75 to 1. Using the results obtained in the single cylinder

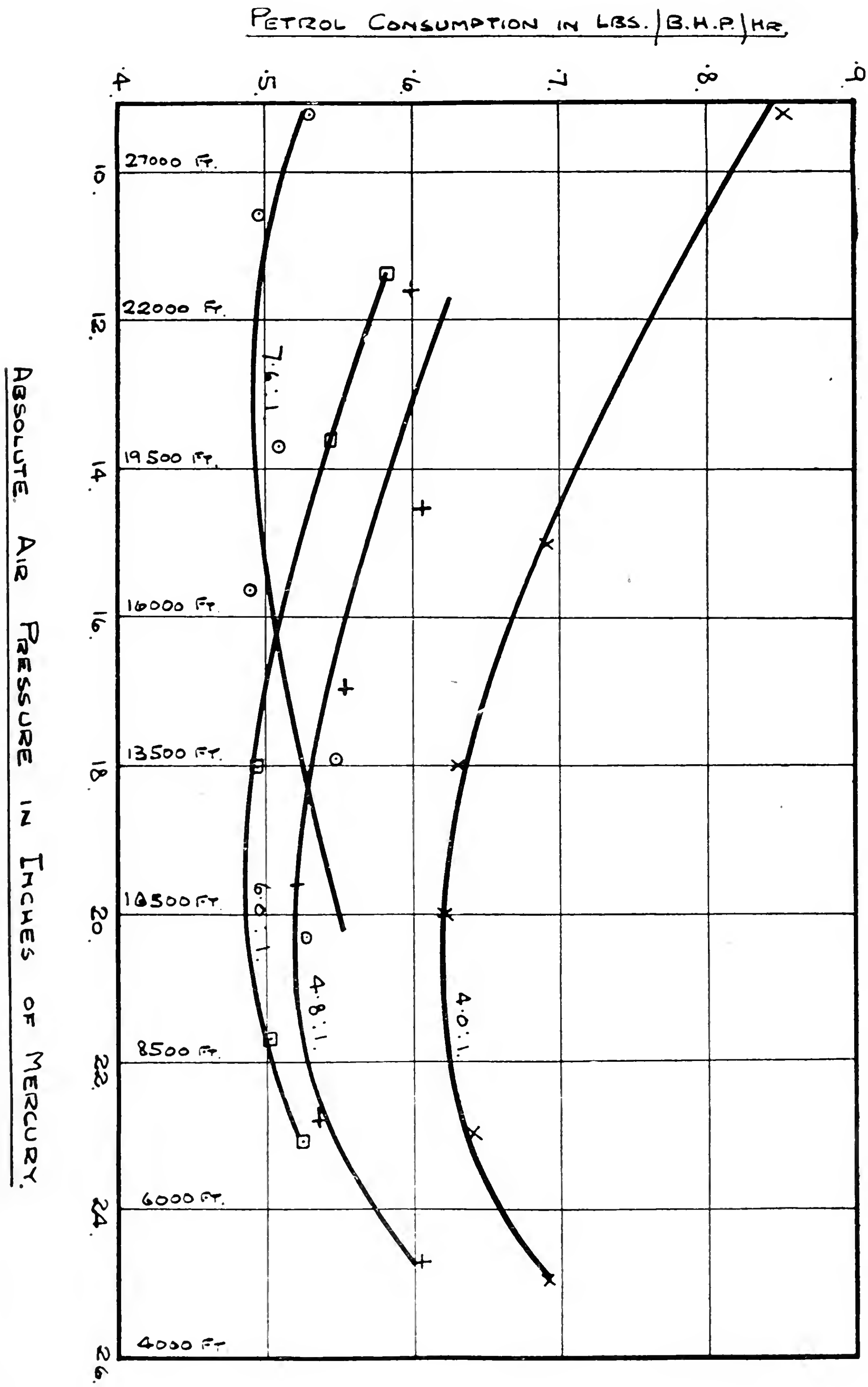


FIG. 4.

unit with a compression ratio of 4.8 as a basis of comparison, the percentage gain in b.h.p. with compression ratios of 6.0 and 7.6, and the percentage loss in b.h.p. with the 4.0 compression ratio have been calculated for various air pressures and are shown graphically in Fig. 6. The plotted results of Fig. 6 show that the gain in power obtainable by the use of high compression increases rapidly as the density diminishes. The results obtained with a ratio of 4.0 : 1 serve to indicate the relative inefficiency of compressions lower than the normal, particularly under low density conditions.

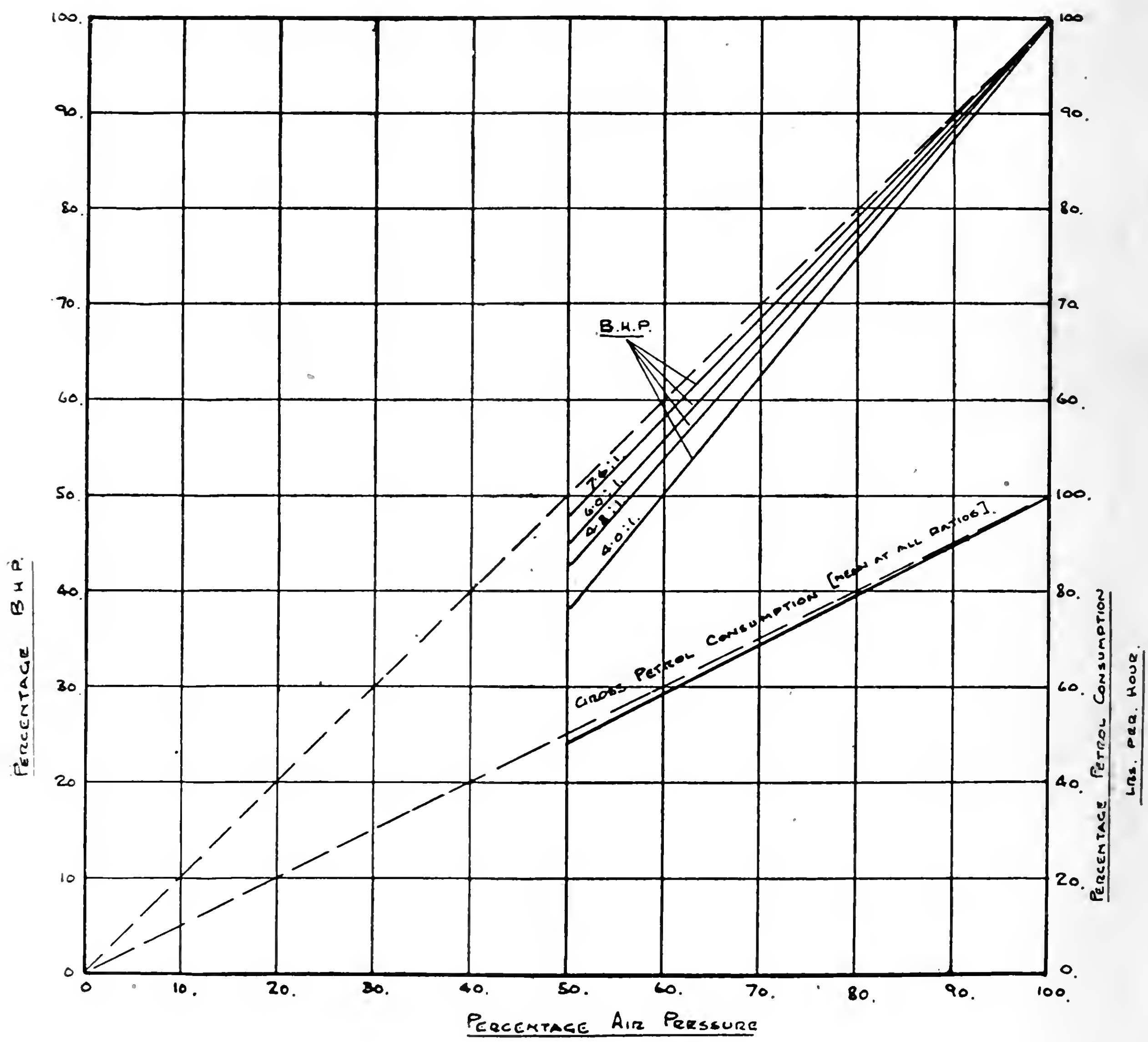


Fig 5.

The dotted lines of Fig. 6 represent the theoretical gain on or loss in b.h.p. with reference to a ratio of 4.8 for the various ratios tested, and refer to constant initial temperature conditions. It is of interest to note that while the observed values are in close agreement with the theoretical values at pressures in the neighbourhood of 20 inches of mercury and with pressures in excess of this, the actual increase in b.h.p. obtainable with increased compression at pressures lower than this exceeds the theoretical increase, the difference increasing with decrease in density. The subject is dealt with at greater length in para. (12).

From Fig. 5 it will be observed that the relationship between percentage power and percentage pressure is a linear one for all compressions and over the range of pressures tested. The rate of decrease of power with pressure is dependent upon compression ratio, decreasing with increase in compression ratio. With

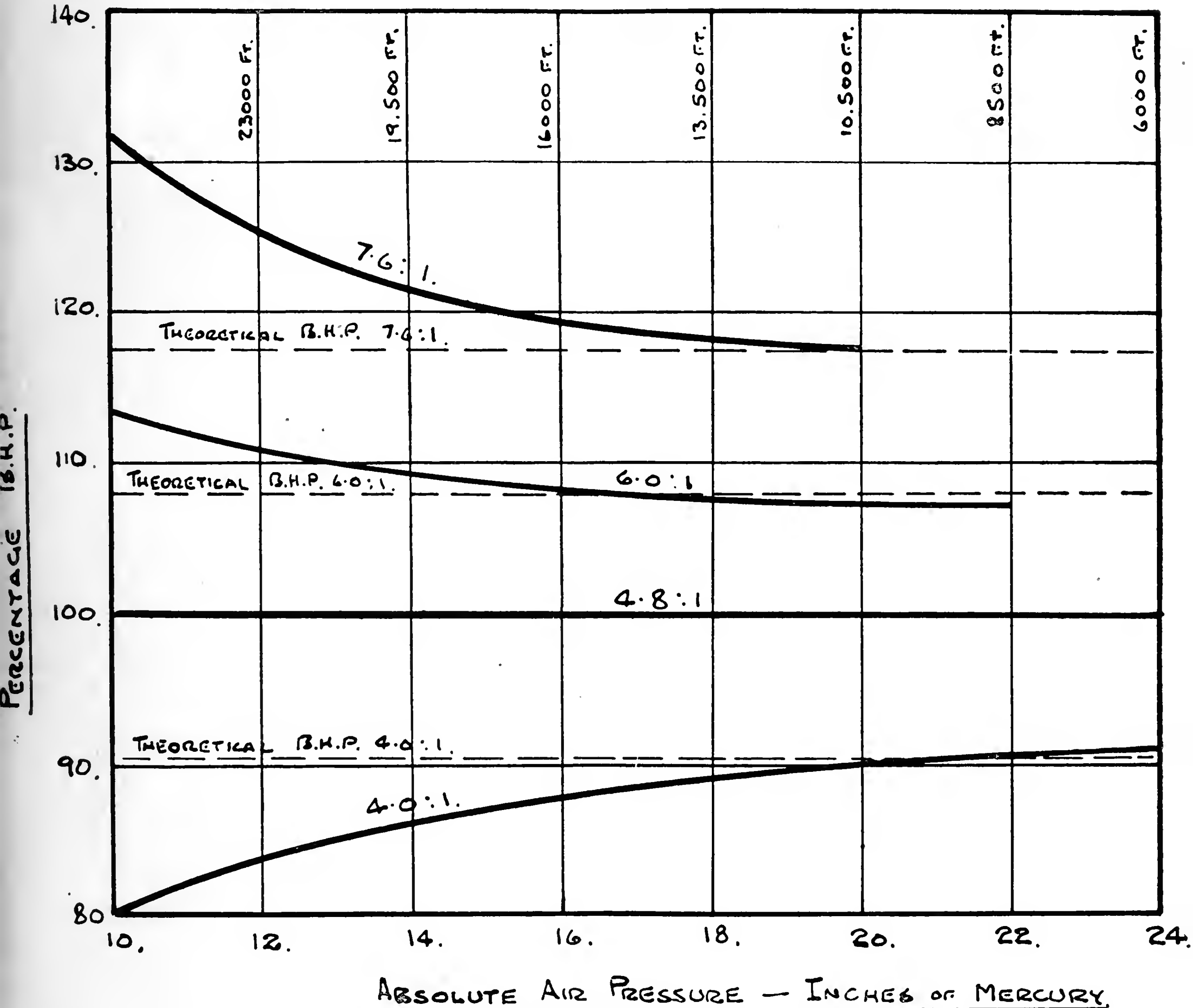


Fig. 6.

a pressure equivalent to 50 per cent. of the standard pressure chosen for comparison, the percentage b.h.p. with each ratio is as follows:—

TABLE 7.

Compression Ratio.	4.0	4.8	6.0	7.6
Percentage b.h.p. ...	38.0	42.5	45.0	48.0

The 300 h.p. Fiat engine with standard compression develops approximately 244 h.p. on the ground at 1,550 r.p.m. Assuming that the effect of density is

the same in the multi-cylinder engine and in the single-cylinder unit, and neglecting the effect of temperature, the probable output of the engine at various altitudes and with various compression ratios is given in Table 8.

TABLE 8.

Altitude in feet.	Compression Ratio. 4.0	4.8	6.0	7.6
10,000 ...	175	194	208	—
15,000 ...	135	152	164	181
20,000 ...	101	118	129	144
25,000 ...	73	89	100	114
30,000 ...	51	65	75	88

The figures given above indicate the importance of high compression in relation to the performance of an aero engine under the conditions obtaining at altitude.

(*b*) Petrol Consumption.

Taken over the range of pressures tested, the petrol consumption per b.h.p. per hour decreases with increase in compression ratio. The means of all observations for each ratio are as follows:—

TABLE 9.

Compression Ratio.	4.0	4.8	6.0	7.6
Mean petrol consumption lbs./b.h.p./hour ...	.70	.56	.52	.51

The gross consumption in lbs. per hour for each test is shown in Fig. 3. The plotted results show that for all compressions the gross petrol consumption for the same absolute air pressure is sensibly constant. It therefore appears that under the reduced density conditions obtaining at altitude, the improvement in the performance of a machine, obtainable by increasing the compression ratio of the engine, is secured without increasing the weight of petrol carried for a given endurance. This enables a greater air mileage per gallon to be obtained, and for the same useful load carried, a greater range of flight than is obtainable with the normal engine.

(11.) Heat Distribution. Thermal Efficiency.

The heat energy supplied to the engine in the form of fuel is expended as follows:—

Heat supplied.

- Heat developed in combustion.
  - Heat equivalent of b.h.p.
  - Heat in exhaust (including latent heat of water formed).
  - Heat transferred from working fluid to engine.
    - Heat dissipated by jacket water.
    - Heat loss due to vaporisation of lubricant.
    - Heat dissipated from exterior surfaces of crankcase, etc.
- Heat loss due to incomplete combustion.

In the present series of tests no exhaust gas analyses were made, and consequently the quantity of heat lost in unburnt gases could not be accurately determined. In drawing up a heat balance for each series of tests, the heat loss in unburnt gases and that lost in radiation have been lumped together and obtained by difference. The heat loss in the exhaust includes the residual heat after passing the calorimeter. The latent heat of vaporisation of the water formed has been deducted as the lower calorific value of the fuel has been employed.

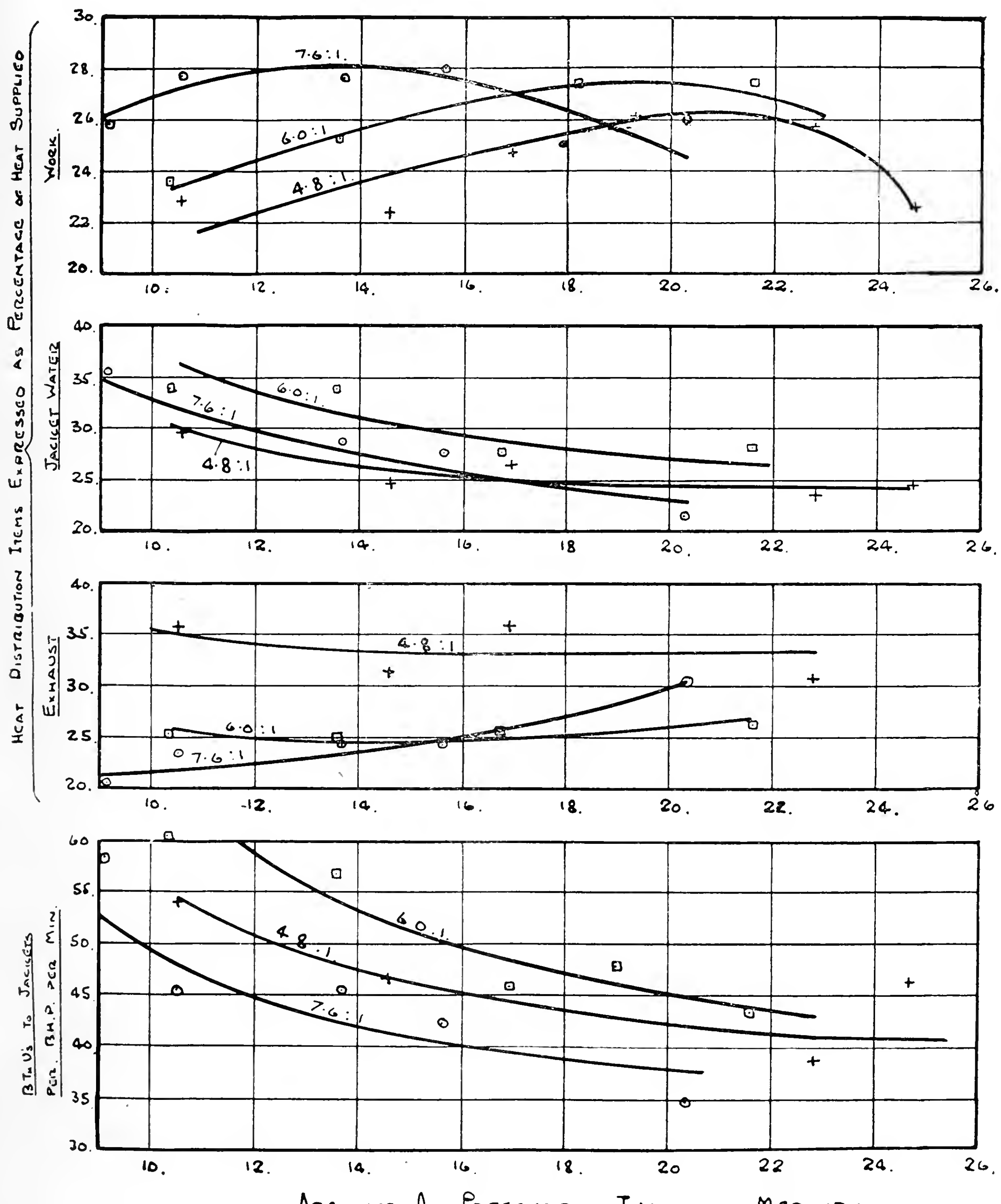


Fig 7.

The heat distribution for the 4.0 : 1 compression ratio was not observed as this ratio is too low to be of practical interest.

The variation in the thermal efficiency, the percentage of the total heat given to the jackets and that lost in the exhaust with varying air pressure and compression ratio are shown in Fig. 7.

The mean brake thermal efficiencies taken over the whole range of pressures tested are 0.268, 0.260 and 0.246, with compression ratios of 7.6, 6.0 and 4.8 respectively.

With regard to the jacket and exhaust losses, the apparent irregularity of the results obtained with the highest compression ratio is probably due to the fact that with this adjustment the sparking plug was partially blanked by the piston at the point of ignition. The piston edge was chamfered off to clear the plug, and this would undoubtedly have a directive effect upon the flame wave. Such directive action would doubtless result in higher piston temperature, and in consequence a greater heat loss to the lubricant. With the lower compression ratios, the standard piston was employed.

A comparison of the results obtained with the 6.0 : 1 and the 4.8 : 1 ratio indicates that the amount of heat given to the jackets per unit of heat supplied, increases with an increase in compression ratio and with a reduction in air pressure. The results also indicate that the amount of heat passing into the jacket water per horse-power per minute increases both with an increase in compression ratio and with a reduction in air pressure as shown in Fig. 7. A comparison of the results obtained with these two ratios is given below.

TABLE 10.

Compression. Ratio.	Heat given to Jacket Water B.Th.U's per Min. Air Press. 13in. Mercury. per B.H.P.	Total.	Air Pressure 18in. Mercury. per B.H.P.	Total.	Air Pressure 23in. Mercury. per B.H.P.	Total.
4.8 : 1	50.5	985	44.2	1282	42.4	1620
6.0 : 1	56.5	1215	47.0	1468	44.1	1809

The three air pressures compared correspond approximately to 21,000, 12,500 and 7,000 feet respectively. At these three altitudes the higher compression ratio gives 10 per cent., 8½ per cent. and 6½ per cent. more power, while the heat given to the jackets per unit of power is 12 per cent., 6 per cent. and 4 per cent. greater than with the lower compression ratio.

An abstract of the heat distribution and its variation with compression ratio is given below. In this case values have been obtained by taking the means of all observations made with each compression ratio.

TABLE 11.

Comp. Ratio.	B.Th.U's Supplied.	B.Th.U's in Work.	B.Th.U's to Jackets.	B.Th.U's Exhaust.	B.Th.U's in Radiation, etc., by difference.
7.6 : 1	100	26.8	25.5	24.7	23.0
6.0 : 1	100	26.0	29.4	25.6	19.0
4.8 : 1	100	24.6	25.1	34.2	16.1

The last column in Table 11 has been obtained by difference. As will be seen, the percentage of the available heat unaccounted for as work, jacket, or exhaust heat is very considerable. The mean air-petrol ratio throughout the tests was probably in the neighbourhood of 12 or 13 of air to 1 of petrol. With a ratio of 13 : 1, the probable exhaust gas analysis is as follows:—

CO_2	CO	H_2	CH_4
12.5%	2.6%	0.9%	0.3%

With this mixture strength, the percentage of the total heat liberated in the cylinder is approximately 90 per cent., leaving some 10 per cent. in the form of unburnt fuel passing into the exhaust. The balance of unaccounted losses is attributed to radiation and to vaporisation of the lubricant from the piston and internal cylinder surfaces. The heat loss due to radiation from the external cylinder and crankcase surfaces was found to be approximately 2 per cent. of the heat supplied under each test condition.

With this correction the heat loss attributable to oil vaporisation is approximately 11 per cent., 7 per cent. and 4 per cent. of the total heat given in each case. These figures, though only approximate, serve to indicate the relatively high thermal losses in the petrol engine attributable to oil vaporisation.

(12.) General Discussion of Data Obtained.

Practically no information is available as to the behaviour of petrol-air mixtures when exploded in a closed vessel. Test results obtained by Messrs. Bairstow and Alexander on the effect of density upon the maximum pressure and rate of explosion in coal-gas-air mixtures are, however, available and are of interest in the present instance as affording a probable explanation of the various phenomena observed in the engine tests discussed.

In these tests a closed explosion vessel having a diameter of 10in. and a length of 18in. was employed, and observations were made with initial pressures ranging from approximately 7lbs. per square inch to 45lbs. per square inch, and for mixtures strength of 6 : 1 and 10 : 1 by volume. The former mixture is approximately that giving maximum explosion pressure. The maximum pressure and the time taken to reach that maximum were recorded by an indicator, while the temperature of explosion was also observed.

The experimental results obtained by Messrs. Bairstow and Alexander show that the proportional temperature drop, *i.e.*, the proportional heat flow from the fluid to the walls, increases with reduction in density and with increase in mean gas temperature.

The relative heat loss to the walls with various initial pressures and with mean gas temperatures of 1,200° C. and 1,600° C. is indicated in Table 12.* The figures given for pressures in excess of 45lbs. per square inch have been obtained by extrapolation.

TABLE 12.

Initial Pressure in lbs./sq. inch.	20	30	40	50	60	70	80
Mean temp. 1,200° C.	2.36	2.03	1.73	1.42	1.21	1.09	1.00
Mean temp. 1,600° C.	—	2.66	2.16	1.74	1.41	1.13	1.01

Relative Heat Loss to Walls.

While the proportional heat flow from the fluid to the walls increases with reduction in density, the absolute heat flow per unit of wall area will evidently decrease with reduction in density as the absolute heat flow depends upon the weight of fluid in contact with the walls, and this is directly proportional to density.

The results discussed above are not directly applicable to the petrol engine, as the fuel tested was a mixture of coal gas and air. Notwithstanding this, the results given are useful in the present instance, as offering an explanation of the observed effect of compression ratio upon the performance of an engine operating under reduced density conditions, and also as suggesting a reason for the difference in performance between one engine and another.

* From data given in "Gas, Petrol and Oil Engines," Sir Dugald Clerk, D.Sc., F.R.S., M.Inst.C.E.

In brief, the experiments of Bairstow and Alexander point to the conclusion that in an internal combustion engine the proportional heat loss to the walls increases as the density of the charge prior to ignition decreases, and that the proportional heat loss increases with increase in the mean temperature of the charge. As applied to the aeronautical engine operating under reduced density conditions the results point to a relative increase in proportional heat loss to the walls as the machine ascends. Such condition corresponds to lower efficiency at altitude than on the ground, and this may be expected to effect either a reduction in power or an increase in petrol consumption or both, apart altogether from the direct influence of density upon charge weight and power output.

In the tests on engines 1 and 2, discussed in para. (1), the rate of decrease in power with decrease in density is lower in engine 1 than in engine 2. Both engines are identical in general design, except that the former is fitted with aluminium cylinders, while in the latter these are of cast iron. Independent tests show that the running temperature of the cylinders is lower in the former than in the latter. At a given density the mean charge temperature in No. 2 engine may therefore be expected to be greater than in No. 1 engine, and since the density effect upon heat loss has been seen to increase with increase in mean temperature, the difference in the performance of the two engines under reduced density conditions is probably attributable in part to this cause. With both engines the relationship between density and power is linear down to a pressure of approximately 70 per cent. of ground pressure, over which range the consumption remains sensibly constant. With densities lower than this, the power in each case diminishes more rapidly, while the consumption increases. The compression ratio at which No. 1 engine was tested was 4.7 : 1 and with No. 2 engine the ratio was 4.4 : 1. The volumetric efficiency of No. 2 engine is considerably lower than in No. 1 engine, due to structural differences in cylinder design in the two engines. As a result of this, at a given atmospheric density, the density of the charge prior to ignition will be somewhat lower in No. 2 engine than in No. 1 engine. The combined effect of higher charge temperature, lower compression ratio, and lower volumetric efficiency in No. 2 engine would therefore appear to produce conditions corresponding to greater proportional heat loss to the walls. The observed difference in performance of the two engines is not of large magnitude, as will be seen by reference to Fig. 2, but is of the order of the probable differences in charge density in the two cases.

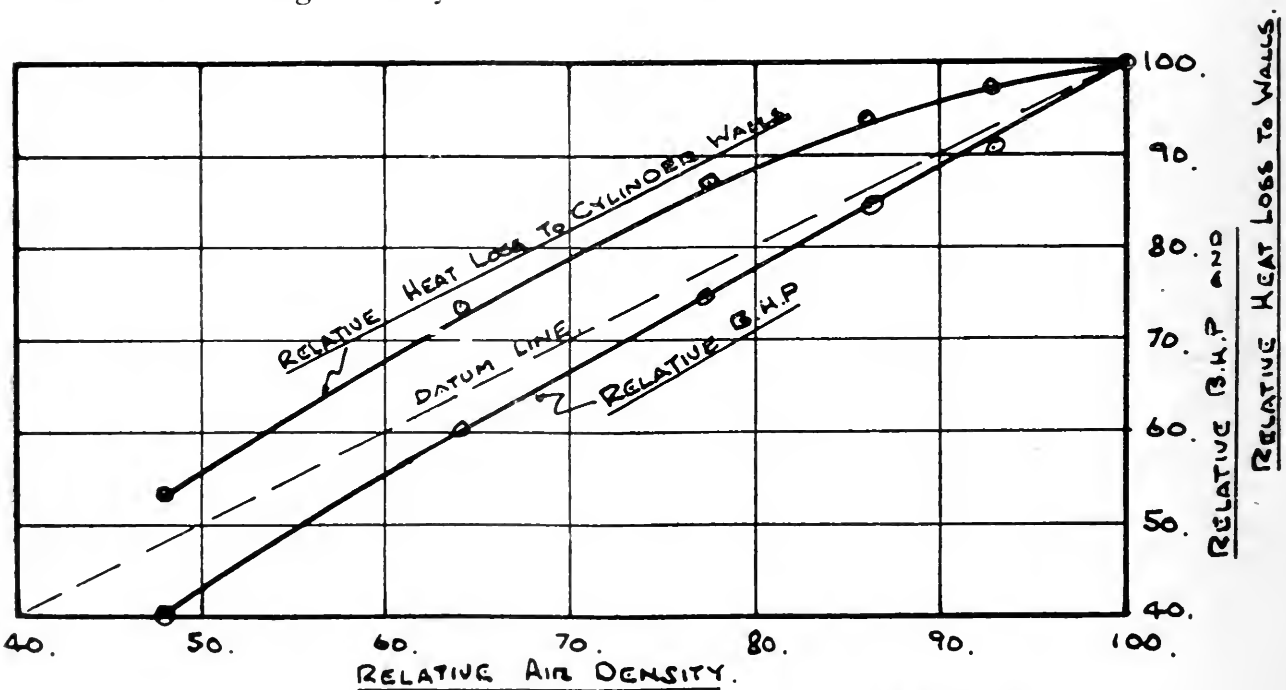


FIG. 8.

In the tests carried out on No. 2 engine, the temperature of the cylinders was measured by means of a series of thermocouples mounted in plugs screwed into the hottest part of the head. On the assumption that the heat dissipated by the cylinder cooling surfaces is proportional to the mean cylinder temperature—the cooling air temperature being constant, and that the mean temperature is proportional to the maximum temperature, the relative heat loss with varying air pressure is shown in Fig. 8.

The corresponding heat loss in the single cylinder Fiat tests is shown in Fig. 9. In both sets of tests it will be seen that the relative heat loss decreases less rapidly than air density, while the b.h.p. falls off more rapidly than density. The proportional heat loss, as represented by the ratio relative heat loss to

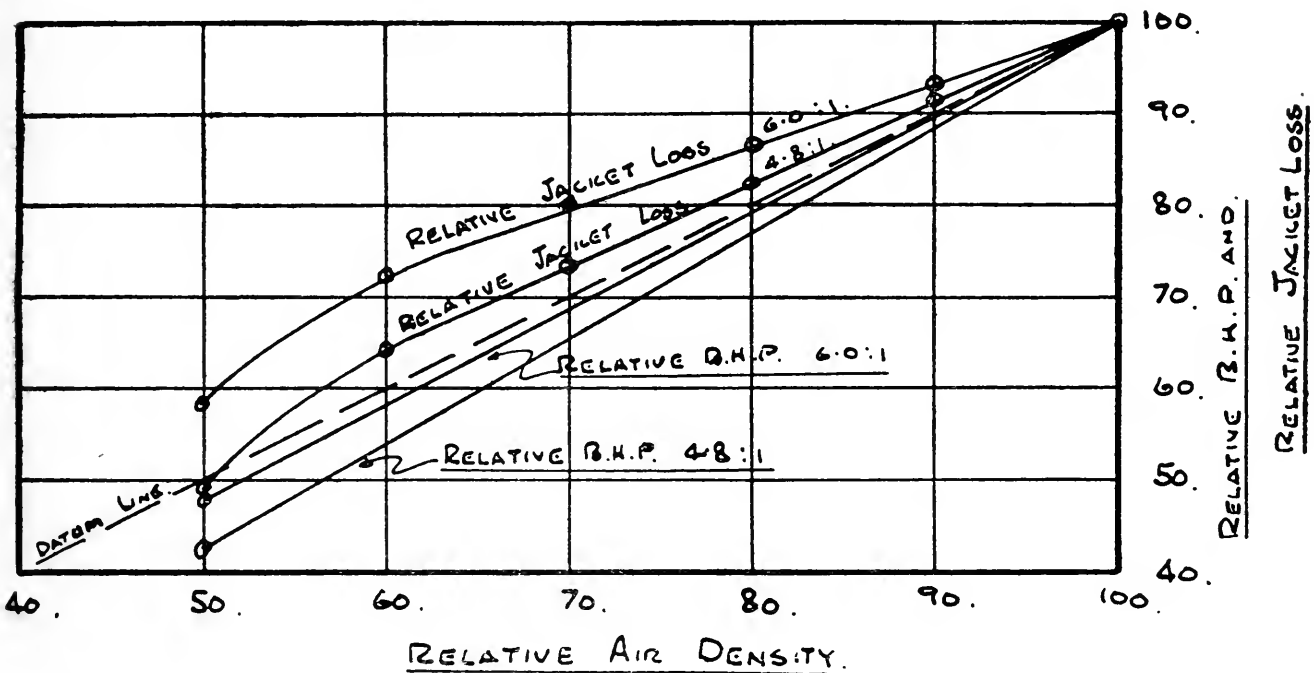


Fig. 9

relative b.h.p., therefore increases as the density diminishes. The observed diminution in relative heat loss at the lowest densities tested is evidently due to the cooling influence of the excess petrol in the charge. From Fig. 9 it will be seen that in the Fiat tests the proportional heat loss is slightly lower with the lower compression ratio which is contrary to what might be expected. This is however partly accounted for by the higher petrol consumption with the lower ratio—.56lbs./b.h.p./hour as against .52lbs./b.h.p./hour with the higher ratio.

In the Fiat tests the heat loss to the jackets varies approximately as $\rho^{.63}$ with the higher ratio, and as $\rho^{.87}$ with the lower ratio, where ρ is the atmospheric density. In the multi-cylinder air-cooled engine tests the mean value of the index of ρ is approximately .64.

In the Fiat tests increase in compression ratio was found to reduce the rate of decrease of b.h.p. with density, as discussed in para. (9). Corresponding to this, the mean petrol consumption per b.h.p. per hour decreased with increase in compression ratio throughout the range of pressures tested. With each ratio the petrol consumption per unit of power first decreases with decrease in density, attains a minimum value, and thereafter increases. The apparent explanation of this phenomenon would appear to be as follows:—Reduction in density entails increased proportional heat loss to the walls, and hence a constant rate of decrease in power involves increased consumption per unit of power. On the other hand,

with diminishing air density the b.h.p. and therefore the cylinder wall temperature decreases, and in consequence the petrol flow may be cut down to correspond more nearly to a mixture giving complete combustion, less excess petrol being required for internal cooling of the charge. The combination of these two effects will evidently result in the phenomenon observed. Similar results, though not so marked, were observed in the multi-cylinder engine tests.

It has already been observed that the density at which maximum thermal efficiency is attained decreases with increase in compression ratio.

The percentage density at which these maxima occur are approximately as follows :—

TABLE 13.

Compression ratio	4.8	6.0	7.6
Percentage of ground density at which maximum thermal efficiency developed ...	68%	60%	43%

The densities given above correspond roughly to the densities at which the compression pressure is the same with each ratio, a result which might be anticipated from the explosion vessel tests of Messrs. Bairstow and Alexander.

The Fiat temperature tests at air temperatures of + 13° C. and + 45° C. indicate that the rate of increase of consumption with diminishing density increases with increase in temperature. This substantiates the explosion vessel tests, which show the temperature effect on the heat loss to the walls to increase with diminishing density, a state of affairs corresponding to a reduction in engine efficiency.

While no direct inference as to the behaviour of petrol-air mixtures can be drawn from the tests of Messrs. Bairstow and Alexander, the points of correspondence between the engine tests and the explosion vessel tests would appear to indicate that the latter are qualitatively applicable to the working fluid in the petrol engine.

(13.) Power Recuperation at Altitude.

The lift of an aeroplane wing is given by $L = K_L\,(\rho/g)\,SV^2$ where K_L is the lift coefficient, ρ/g is the absolute air density, S is the wing area, and V is the air speed in miles per hour. The value of K_L varies with the angle of incidence. Assuming that the angle of incidence corresponds to that giving maximum value of the lift-drag ratio, conditions of maximum efficiency in level flight demand that ρV^2 shall be constant as the aeroplane ascends.

In an aeroplane of given gross weight a definite minimum speed exists below which horizontal flight is not possible. In commercial craft it may be taken that the rate of climb is subservient to conditions of maximum efficiency at the height at which the machine is designed to operate. Under these circumstances, so far as engine weight is concerned, maximum economy is secured if the motive power is such as to maintain the relationship.

$$V_h = V_g\sqrt{(\rho_g/\rho_h)}$$

Where V_h is the true air speed at the height h, and V_g is the minimum permissible air speed near the ground, ρ_h and ρ_g being the densities at height h and on the ground respectively.

Table 14 has been prepared to show the variation in horse-power absorbed and horse-power available in a typical case. The following data has been assumed :—

Aeroplane :—Gross weight of aeroplane 2,000lbs.
Wing section R.A.F. 15 aerofoil.
Wing area 250 sq. feet.

Engine:—300 b.h.p. on full throttle on the ground.
Airscrew efficiency 80 per cent. at all densities.
Variation in b.h.p. with pressure assumed to be the same as that of engine 3 of para. (1).
1 per cent. increase in power for each 10° C. drop in air temperature assumed.

With the above wing section, the lift-drag ratio is a maximum with an angle of incidence of approximately 3°. With this angle of incidence and with a gross load of 2,000lbs., the minimum speed in level flight near the ground is approximately 90 m.p.h. The relationship ρV^2 = constant is assumed.

TABLE 14.

Altitude in feet	0	5,000	10,000	15,000	20,000
Density relative to ground density	1.000	.855	.721	.617	.524
True vel. m.p.h.	90	97	106	115	124
H.P. absorbed	93	100	110	118	129
Thrust h.p. available	240	199	163	128	98

Comparison of the figures given for h.p. absorbed and h.p. available shows that up to a height of approximately 17,000 feet, the h.p. available is in excess of that required to maintain the machine in horizontal flight, the excess representing the h.p. available for climbing. At 17,000 feet the thrust h.p. is just sufficient to overcome the resistance to flight under the conditions specified, this being the maximum height at which level flight can be maintained.

The data given shows that if the machine is required to have a ceiling height of 17,000 feet, an engine capable of developing 300 b.h.p. on the ground is required, whereas the power absorbed in maintaining the minimum speed of flight near the ground is 93 h.p. Under the assumed conditions the machine is therefore considerably over-engined near the ground. If the machine were fitted with an engine developing 120 h.p. at the airscrew, and if means were adopted to maintain the power constant at all altitudes, the machine would still have a ceiling of approximately 17,000 feet. In this case, however, the excess of power available at any altitude up to the ceiling height is lower than in the previous case, and in consequence the maximum speed and rate of climb are lower. For commercial craft, and particularly for long distance service, the lower rate of climb obtainable with a light constant power engine would not appear to be a serious objection. The advantage of such an engine when operating at altitude is obvious.

In military scouting craft it is evidently desirable to secure the maximum possible rate of climb at all altitudes at which the machine is required to manœuvre, irrespective of the conditions of maximum economy outlined above. This necessitates the use of a power unit of much greater output than is required to maintain the minimum speed of flight. In such craft, any means adopted to recuperate the loss in power due to reduced density is evidently advantageous as effecting a reduction in engine weight for a given duty, or as affording a means of increasing the rate of climb or of adding to the ceiling height of the machine.

(14.) Supercompression as a Means of Power Recuperation at Altitude.

The test results discussed in para. (9) *et seq.* indicate the high relative merits of the supercompression engine when operating under the reduced density conditions obtaining at altitude, and suggest the possibility of recuperating the power loss in the normal engine by employing some means of increasing the compression pressure as the machine ascends. In practice two general methods are available.

(*a*) By employing a mechanism by means of which the stroke, and therefore the compression ratio, may be increased as the density diminishes.

(*b*) By permanent adjustment of the engine to give a high ratio of compression, the compression pressure being controlled by throttling from the ground up to that height at which the engine may be safely run on full throttle.

Variable stroke gear offers the best possibilities of realising the advantages of supercompression. As applied to the rotary or radial engine, the control mechanism is comparatively simple and the increased weight is not prohibitive.

In the Damblanc-Mutti variable stroke rotary engine, the master rod big-end is eccentrically mounted on the crank pin, the eccentricity being controlled by a hand-operated gear train. The range of compression ratio obtainable in this engine is from 4.8 : 1 to 7.0 : 1 and the weight of the engine together with the additional mechanism is 2.52lbs. per brake horse-power.

The application of variable stroke gear to the single line or multi-line engine would appear to be impracticable, due to the complication of mechanism involved, and in such engines a permanent adjustment of the compression ratio would appear to be essential. Where the engine is permanently adjusted to give a high ratio of compression, the charge weight may be reduced either by throttling at the carburettor or preferably by employing a stepped inlet cam so designed as to limit the compression pressure at all air densities in excess of that at which the engine is designed to run on full throttle. The fitting of stepped cams and control gear would add but little to the complexity of the mechanism of the normal engine, and the increased weight would be negligible.

(15.) The Effect of Throttling on the Performance of a High Compression Engine.

In the tests discussed in para. (9) *et seq.* the point at which detonation under full throttle conditions commenced was taken as the limiting pressure at which the engine could be operated on full throttle. An additional observation, corresponding to an increase of pressure of approximately two inches of mercury, could always be obtained by retarding the spark by approximately 5°, but further retardation resulted in a drop in power.

The limiting pressures and the approximate corresponding altitudes for each compression ratio are given below:—

TABLE 15.

Comp. Ratio.	Absolute Air Press. Inches Mercury.	Approx. Corres. Alt. in feet.	B.H.P. developed.
7.6 : 1	19.0	12,000	36
6.0 : 1	22.5	7,000	40
4.8 : 1	25.0	4,500	42

Tests were carried out with a compression ratio of 6.0 : 1 to determine the maximum power obtainable by throttling under ground conditions. In these tests the pressure on the exhaust side of the engine was maintained at that of the atmosphere. The disturbing influence of pressure oscillations in the neighbourhood of the jet, which accompanies the throttling of a single-cylinder engine, was minimised by connecting the carburettor to an air vessel of large capacity fitted with a throttle valve by means of which the pressure on the inlet side of the engine was regulated. The carburettor throttle remained full open throughout the tests. The results obtained may therefore be taken as substantially representing throttled conditions in a multi-cylinder engine. In each test the spark advance and petrol flow were adjusted to give maximum load. The results obtained are given in Table 16.

TABLE 16.

Absolute Pressure Inches of Mercury. Exhaust.	Absolute Pressure Inches of Mercury. Induction.	Depression in Induction Pipe. ins. Mercury.	B.H.P.	Fuel cons. lbs./B.H.P. hr.	Spark Advce. Degrees.	Remarks.
29·37	18.80	10.57	26.96	.618	35	
	20.97	8.40	32.62	.620		
	22·59	6.78	36.64	·743		
	23·61	5·76	39·00	·753		
	24·57	4.80	41·50	·748		Slight Detonation.
	25·47	3·90	43·00	·700	28	
	25·47	3·90	43·00	·700	26	
	26.01	3·36	44·40	·705	25	Max. Possible Throttle Opening.

Comp. Ratio 6.0 : 1. Air Temp. 13·4°C. R.P.M. 1550.

Referring to Table 16 it will be seen that the depression in the induction system could be reduced to approximately 5in. of mercury before detonation with full spark advance commenced. Beyond this point it was found necessary to retard the spark in each successive test to prevent excessive detonation. Simultaneously, and for the same reason, it was found essential to increase the mixture strength as shown in column (5) A maximum brake horse power of 44.4 was developed with the spark retarded to 25°, *i.e.*, retarded 10° from its normal advance, with a depression in the induction system of 3.36 inches of mercury, and the petrol flow adjusted to give a consumption of approximately .705lbs. per b.h.p. per hour. Further, throttle opening on any mixture that would ignite resulted in overheating, severe detonation, and eventually in pre-ignition. In a similar series of tests carried out with a compression ratio of 7.6 to 1, the maximum power developed under throttled conditions was 37 b.h.p. with the spark retarded 10° and with the carburettor jet adjusted to give a consumption of .96lbs. per b.h.p. per hour. With this adjustment, running conditions were somewhat unsteady with a tendency to misfire.

Comparing the results obtained with those given in Table 15, it will be seen that with the 7.6 compression ratio the maximum power developed under throttled conditions on the ground, corresponds to the maximum power developed at the lowest altitude at which the engine can be safely operated on full throttle. With the 6.0 : 1 compression ratio considerably higher power can apparently be developed under throttled conditions on the ground. Quite generally it may be taken that a high compression engine when throttled on the ground will develop at least as much power (at constant speed) as it will develop at a given altitude on full throttle, and that this power can be maintained constant by increasing the throttle opening from the ground to that height at which the engine may be safely run all out.

From the above figures it will be realised that with a high compression engine the carburettor characteristic must be such as to meet throttled conditions on the ground and in climbing.

The maximum compression pressure that can advantageously be employed in any engine can only be determined by experiment. The present series of tests indicate that in the 300 h.p. Fiat engine the best compression ratio is probably in the neighbourhood of 6.5 : 1. With this compression ratio the engine, if throttled on the ground to prevent detonation, would probably develop a maximum b.h.p. sensibly equal to that of the normal engine and would maintain constant power up to an altitude in the neighbourhood of 10,000 feet. In this engine the position of the plugs is such as to give bad combustion conditions with compression ratios

higher than about 6.0 : 1. In an engine with the plugs situated in the head, much better results than those obtained are to be anticipated.

(16.) Effect of Fuel Composition on the Performance of a High Compression Engine.

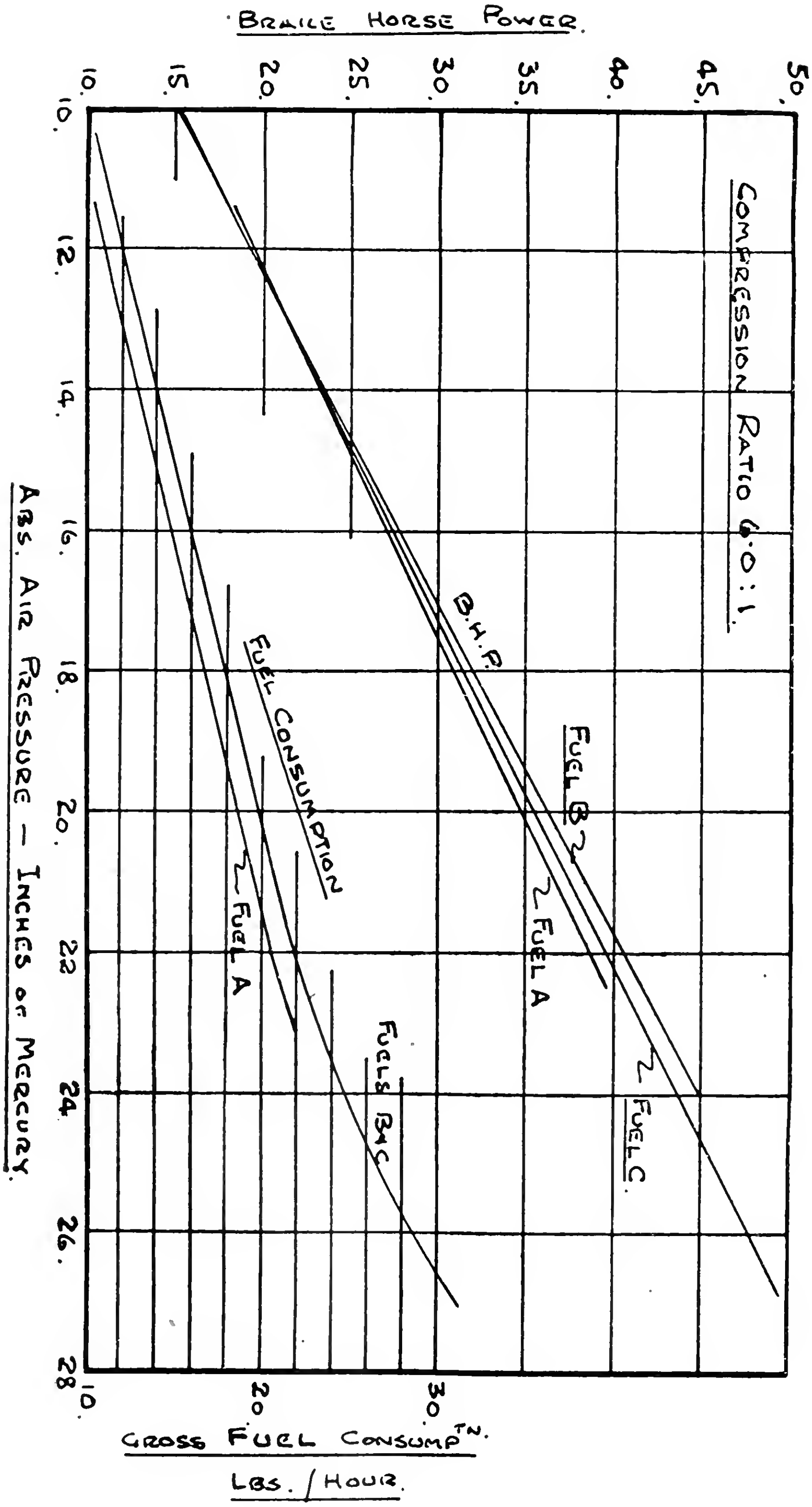
As already discussed, the spontaneous ignition temperature of the fuel has a large controlling influence upon the extent to which the compression ratio of a petrol engine may be raised. Experience shows that under ground pressure conditions, the power output of an engine and its thermal efficiency, may be increased by the employment of a fuel of high spontaneous ignition temperature such as benzole or a mixture of petrol and benzole, in place of standard aviation spirit. The use of such a fuel in a high compression engine would appear to be advantageous in that the engine might be operated on full throttle at a greater air density than is permissible with standard spirit.

To investigate this point, tests were carried out on the single-cylinder Fiat engine at compression ratios of 6.0 and 7.6 : 1 on two fuels having a higher spontaneous ignition temperature than Shell Aviation Spirit. The density and calorific value of Shell Aviation Spirit and the two test fuels are given below.

Reference Letter.	Fuel.	Density.	Cal. Value B.Th.U.'s/lb.
A.	Shell Aviation.	·715	18.600
B.	20% Benzole + 80% Shell Aviation.	·745	18.300
C.	Cracked Fuel of the Olefine Series.	·707	18.600

The spontaneous ignition temperature of the three fuels was not determined, but it was known that (A) had the lowest and (C) the highest spontaneous ignition temperature of the series. The tests were conducted at constant temperature and over a pressure range down to approximately 10 inches of mercury. The results obtained are shown graphically in Figs. 10 and 11.

With both test fuels the gain in power as compared with standard spirit was found to be small, averaging 4 per cent. with fuel (B) and 2 per cent. with fuel (C) in both sets of tests at an absolute air pressure of 20 inches of mercury. At a pressure of 11 inches of mercury with the higher compression ratio, and at a pressure of 13 inches of mercury with the lower ratio, the power developed was identical with the three fuels. Pressures lower than the above-mentioned favoured standard fuel. The results obtained bear out previous experience in the testing of 30 per cent. benzole mixture on the test-bench and in flight, namely, that while this fuel gives considerably more power under ground conditions, in the air, any difference in performance between this and standard aviation spirit is within the limits of observational error. This is apparently due to the fact that the addition of any percentage of benzole to standard spirit raises the spontaneous ignition temperature of the fuel. Under full-throttle ground conditions, particularly with compression pressures higher than normal, the mixture strength with 20 per cent. benzole fuel can be reduced more nearly to that giving maximum power than is the case with standard fuel. With the latter, in order to prevent excessive detonation, it becomes necessary to increase the petrol flow to such an extent as to cause a drop in power. Under the reduced pressure conditions obtaining at altitude, the power developed is lower than under ground pressure conditions, the temperature of the cylinder walls is lower, and in consequence the temperature of the charge does not rise to such an extent as to cause detonation. Under such circumstances the spontaneous ignition temperature of the fuel, as an independent factor, has less influence than under full-throttle conditions on the ground.



Brake Horse Power
10 15 20 25 30 35 40 45 50
Compression Ratio 6·0 : 1.
B.H.P.
Fuel B
Fuel A
Fuel C
Fuel Consumption
Fuel A
Fuels B & C
Abs. Air Pressure — Inches of Mercury.
10 12 14 16 18 20 22 24 26 28
10 20 30
Gross Fuel Consump^tn.
Lbs./Hour.

FIG. 10.

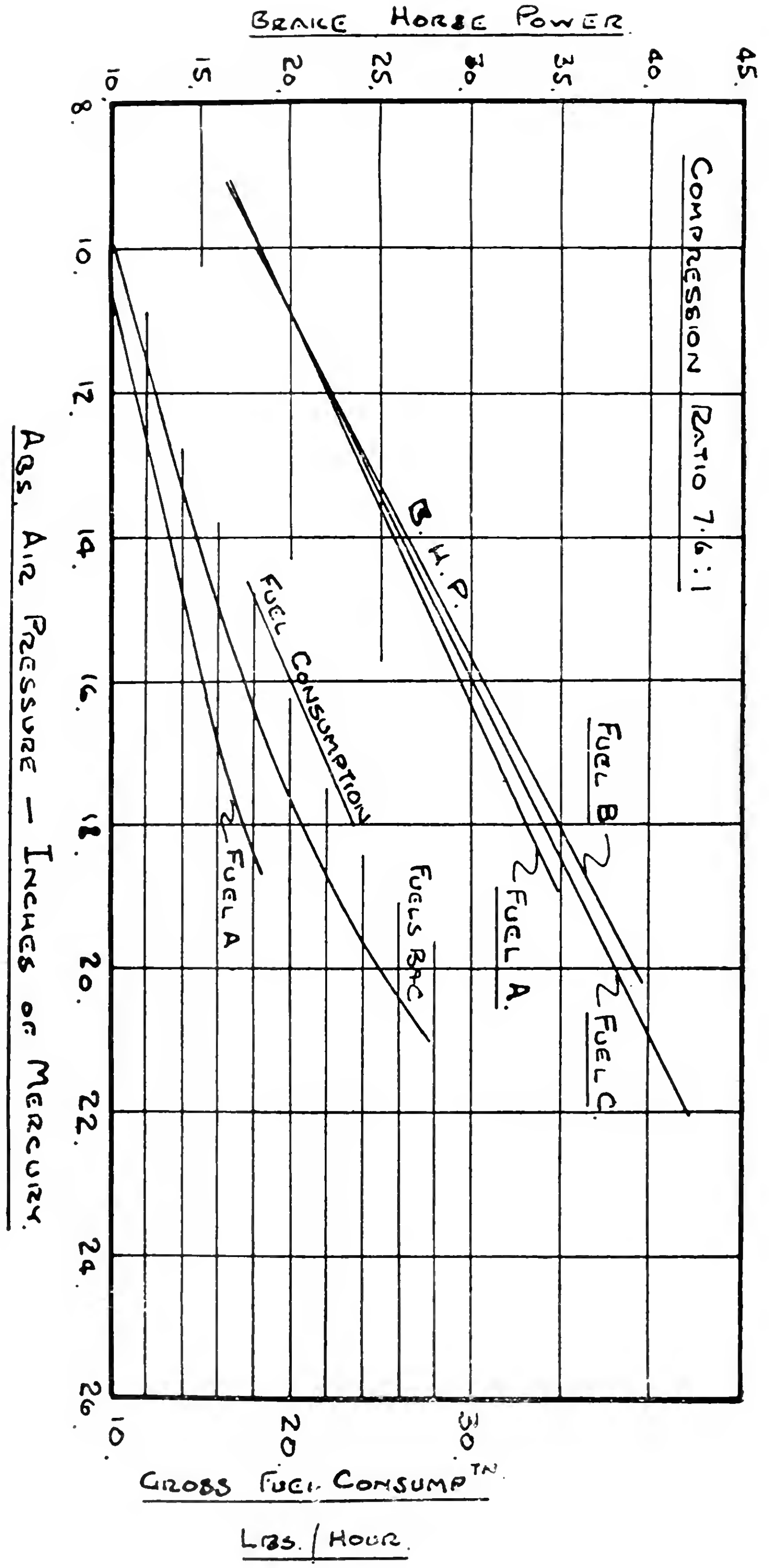

Brake Horse Power
10. 15. 20. 25. 30. 35. 40. 45.
Compression Ratio 7.6 : 1
B.H.P.
Fuel Consumption
Fuel B
Fuel A.
Fuel C.
Fuels B & C
Fuel A
Abs. Air Pressure — Inches of Mercury.
8. 10. 12. 14. 16. 18. 20. 22. 24. 26.
10. 20. 30.
Gross Fuel Consump^tn.
Lbs./Hour.

Fig. 11.

Independent single cylinder tests on 20 per cent. benzole mixture showed that under full-throttle ground density conditions, an increase in power could be obtained by slightly increasing the spark advance with reference to its normal position for standard spirit. In the present series of tests, while this point was not specially investigated, no noticeable increase was obtained by increasing the spark advance under reduced density conditions.

The fuel consumption per b.h.p. per hour was found to be somewhat higher on fuels (B) and (C) than on standard spirit with both compression ratios and at all air densities over the range tested. The gross fuel consumed per hour under each test condition is shown in Figs. 10 and 11, while the heat loss to the jackets per b.h.p. per minute, and the fuel consumption per b.h.p. per hour with a compression ratio of 6.0 : 1 are shown graphically in Figs. 12 and 13. From Fig. 12 it will be seen that the consumption per unit of power is sensibly the same on fuels (B) and (C) and averages 10 per cent. higher than on standard spirit.

Throughout the range of densities tested, the heat loss to the jackets per unit of power was found to be lower with fuels (B) and (C) than with standard spirit. At pressures of 22, 18, and 14 inches of mercury the difference amounts to 36 per cent., 32 per cent. and 27 per cent. respectively. This is probably due in large measure to the difference in consumption as affecting charge temperature, and partly to a difference in the type of explosion with the different fuels.

The heat loss in the exhaust was not determined. It may be presumed, however, that the exhaust losses were relatively greater with fuels (B) and (C) than with standard spirit, due both to higher exhaust temperature and to a greater loss on account of unburnt fuel.

The heat distribution with the higher compression ratio is not discussed as with this ratio explosion conditions were abnormal as already indicated.

The limiting air pressure at which the engine could be operated on full throttle was found to be somewhat higher with both compression ratios on fuel (C) than on standard aviation spirit as indicated in Figs. 10 and 11. The benzole mixture occupies a position intermediate between standard aviation spirit and fuel (C). The following is an abstract of the results obtained showing the maximum b.h.p. obtained on each fuel.

TABLE 17.

	Comp. Ratio 6.0 : 1			Comp. Ratio 7.6 : 1		
Fuel.	Abs. Air Press ins. Mercury.	Correspond'g Altitude in feet.	B.H.P.	Abs. Air Pressure ins. Mercury.	Correspond'g Altitude in feet.	B.H.P.
A.	22.5	7,000	39.8	19.0	12,000	35.2
B.	24.0	5,500	45.0	20.0	10,000	39.2
C.	25.5	4,000	46.8	22.0	8,000	42.2

From the above it appears that fuels of high spontaneous ignition temperature are of value when employed in a high compression engine in that they permit of the engine being operated on full throttle at a greater density than is possible with standard fuel, and in consequence the thrust horse-power at the minimum permissible altitude on full throttle is increased. Assuming constant air speed, the relationship between the h.p. absorbed by the aeroplane and the maximum b.h.p. available on full throttle with the three fuels tested is as follows :—

TABLE 18.

	Comp. Ratio 6.0 : 1			Comp. Ratio 7.6 : 1		
Fuel.	Altitude in ft.	Relative h.p. abs.	Relative h.p. avail.	Altitude in ft.	Relative h.p. abs.	Relative h.p. avail.
A.	7,000	100.0	100.0	12,000	100.0	100.0
B.	5,500	106.6	113.3	10,000	105.3	111.3
C.	4,000	113.3	117.5	8,000	115.7	120.0

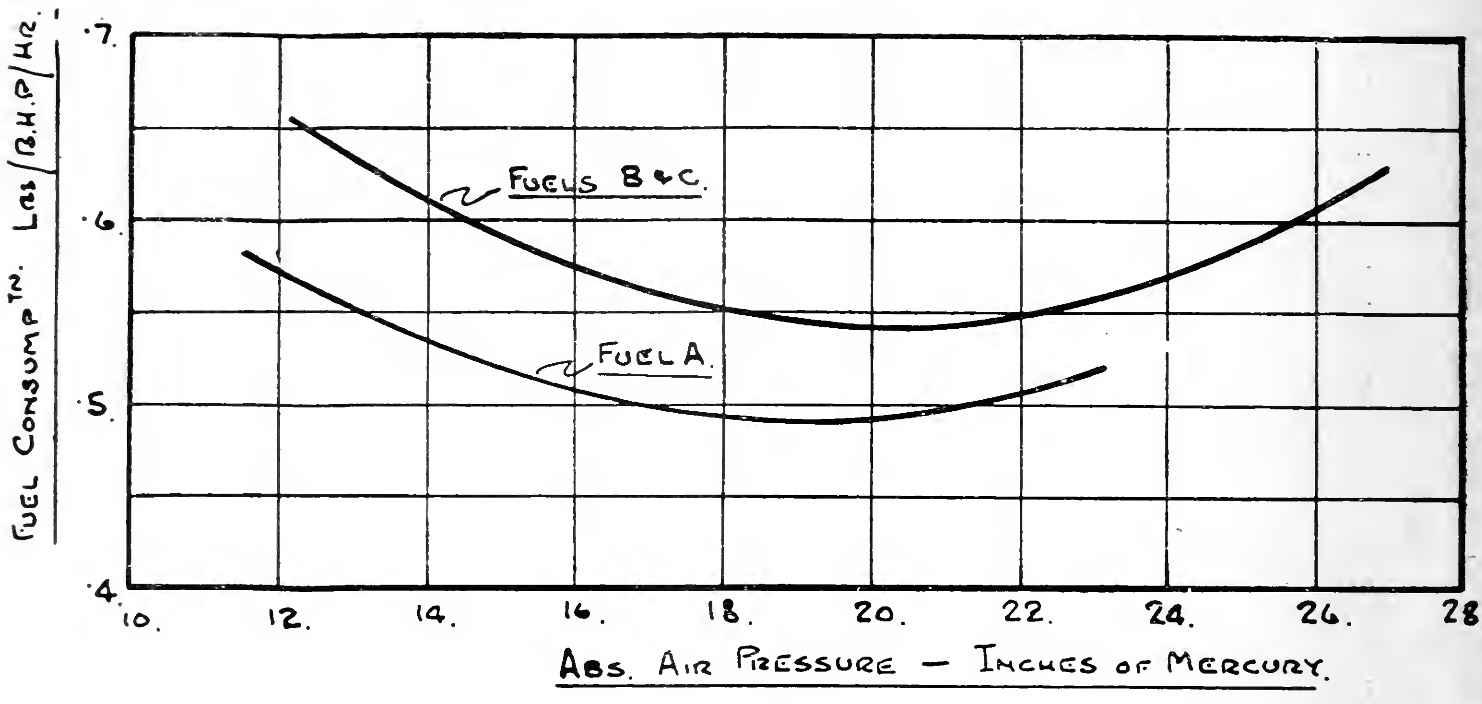

Fuel Consumpᵀᴺ. Lbs/B.H.P/Hr.
·7.
·6.
·5.
·4.
Fuels B & C.
Fuel A.
10.
12.
14.
16.
18.
20.
22.
24.
26.
28
Abs. Air Pressure — Inches of Mercury.

Fig. 12.

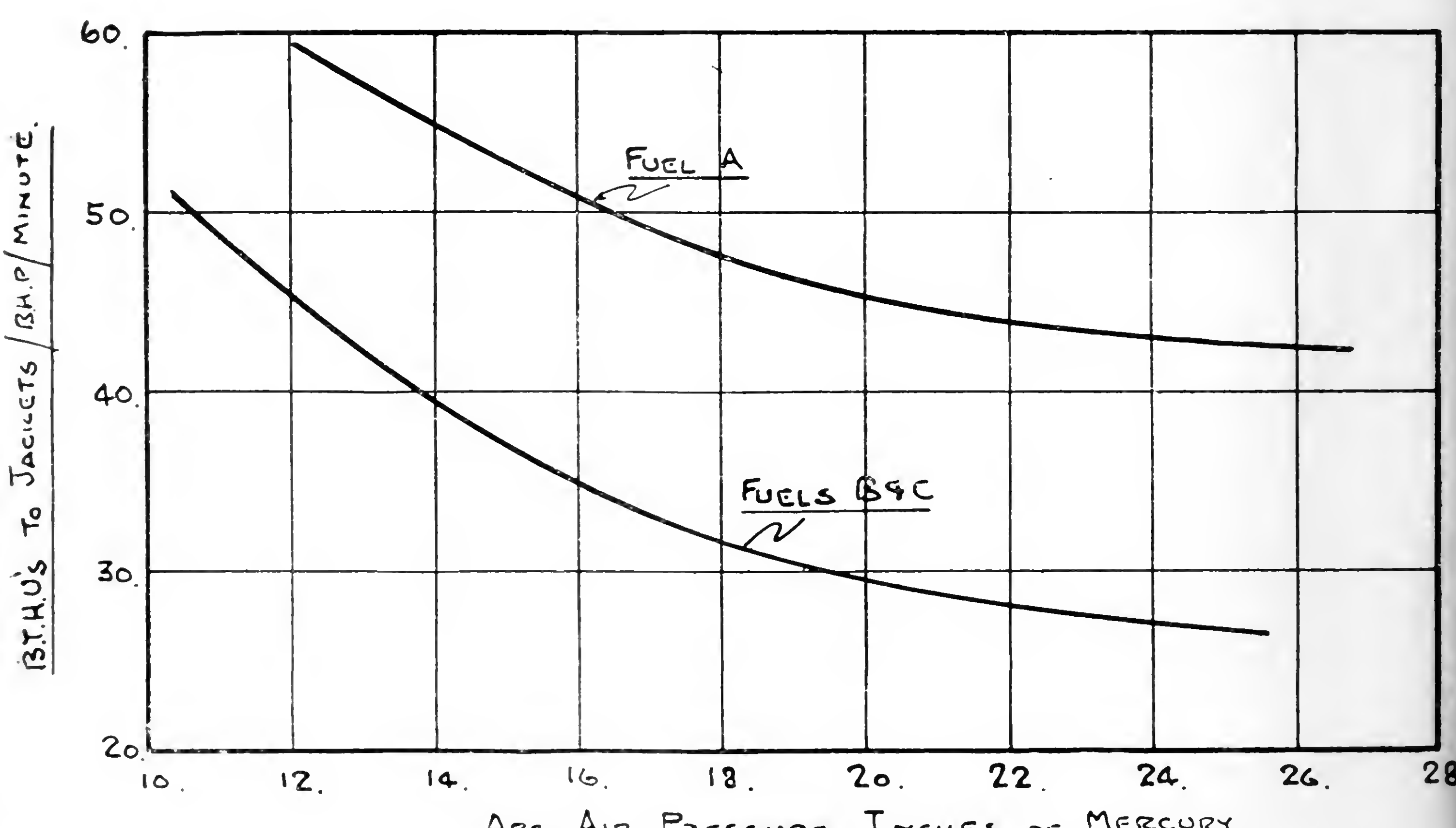

B.T.H.U's to Jackets/B.H.P/Minute.
60.
50.
40.
30.
20.
Fuel A
Fuels B & C
10.
12.
14.
16.
18.
20.
22.
24.
26.
28.
Abs. Air Pressure—Inches of Mercury

Fig. 13.

From the figures tabulated above it will be seen that the excess of power available with fuels (B) and (C) for giving increased speed, as measured by the difference between the h.p. available and that absorbed at the given speed, averages 6 per cent. with fuel (B) and $3\frac{1}{2}$ per cent. with fuel (C). Fuels of high spontaneous ignition temperature offer the further advantage of increased horse-power with the engine throttled. With both fuels tested, the heat loss to the jackets per unit of power is some 30 per cent. lower than with standard spirit, giving a corresponding reduction in the size of radiator required. This is an important advantage, particularly as the cooling of a high-compression or super-charged engine is a matter of some difficulty.

Notwithstanding the above advantages it is improbable that the gain to be obtained by the use of an alternative fuel such as those tested would compensate for the increased fuel consumption.

(17.) The Cooling of Supercompression Engines.

(a) Water-Cooled Engines.

The quantity of heat dissipated by a radiator is proportional to $\theta \rho V^n$ where θ is the temperature difference between water and air, ρ is the air density, and V is the air speed.

The index n increases with air speed and has an average value of .8.*

If the machine climbs at constant indicated air speed, V varies as $\rho^{-\frac{1}{2}}$, and the rate of cooling is given by

$$K\theta\rho \cdot \rho^{-\cdot 4} = K\theta\rho^{\cdot 6}$$

The heat loss to the walls of an aero engine differs in different engines as discussed in para. (12), but may be taken to vary as $\rho^{\cdot 6}$. It is thus seen that θ is independent of density.

The boiling point of water diminishes with altitude due to reduction in pressure, the drop amounting to approximately 5°F. for each 8,000 feet increase in height. The drop in air temperature with increase in height is, however, slightly greater than this, and therefore compensates for the drop in boiling point. Taking the boiling point of water as the higher limit of temperature and the air temperature as the lower limit, the temperature difference between water and air available for cooling purposes is thus seen to be sensibly constant at all altitudes and approximately equal to 160°F. If, therefore, the radiator of a normal aero engine is sufficient to dissipate the heat given to the jackets under full-throttle conditions on the ground with the engine working at its maximum temperature, the cooling surface is adequate to meet the conditions obtaining at altitude.

In the super-compression engine the b.h.p. is maintained constant up to a definite altitude, beyond which the power falls off with diminishing density as in the normal engine. Under these circumstances the radiator must be of such a capacity as to dissipate the heat given to the jackets corresponding to the maximum output of the engine at the lowest density at which the full power is developed. The radiator of a constant power engine is therefore much larger than is required by a normal engine developing the same maximum power. The following figures have been deduced by Dr. A. H. Gibson as representing the necessary increase in radiator surface in such an engine developing constant power up to the altitudes shown.†

* Professor A. H. Gibson, D.Sc., M.Inst.C.E., M.I.Mech.E. Advisory Committee for Aeronautics, I.C.E. Report No. 407.

† Advisory Committee for Aeronautics, I.C.E. 121.

TABLE 19.

Engine Developing Constant Power up to	Percentage Increase in Radiator Size.
6,000 feet.	40%
9,000 feet.	55%
12,000 feet.	70%

The relative importance of the size and weight of the radiator can only be adequately discussed in relation to the resistance of the aeroplane and the resistance of its accessories, the gross weight carried, etc., etc. Under certain circumstances increase in radiator weight and resistance to the required extent might prove prohibitive.

(*b*) Air-Cooled Engines.

In the water-cooled engine the permissible range of wall temperature is not determined by the limiting temperature at which the cylinder, as such, is capable of operation, but is rather governed by the efficiency of the jackets, the capacity for heat absorption of the jacket fluid, and the cooling capacity of the radiator. In flight the radiator must be of such a size as to maintain the temperature of the jacket fluid below its boiling point under the varying conditions encountered. In a water-cooled engine boiling of the jacket fluid not only gives rise to bad circulation but also leads to loss of water.

In the air-cooled engine no such restrictions obtain, the engine being capable of efficient operation over a wide range of wall temperature. The following table shows the variation in maximum cylinder wall temperature with increasing altitude in an aluminium air-cooled engine designed to maintain constant power up to the various altitudes given. The figures have been deduced by Dr. A. H. Gibson from results obtained on a normal engine tested in flight.*

TABLE 20.

Altitude in feet.	Max. Cylinder Temp. °C.
2,500	160
6,000	170
9,000	181
12,000	193

The data given is based on the assumption that the cowl is identical in each case, and that the machine climbs at constant indicated air speed. Bench tests carried out on the engine to which the above figures refer showed this to be capable of efficient operation with a maximum wall temperature as high as 220°C. As a power-recuperating unit the air-cooled engine offers the great advantage of improved aeroplane performance at altitude without materially increasing the weight and resistance of the power plant and its accessories. With the water-cooled engine maintenance of power with diminishing density involves increase in the weight and resistance of the radiator as already discussed. The air-cooled unit offers the further advantage of immunity from freezing at high altitude.

(18.) Airscrew Torque and Speed.

The efficiency of an airscrew at a given density decreases with increase in speed of revolution. Under reduced density conditions, for constant efficiency in level flight at various altitudes, the airscrew speed should vary in accordance with the relationship ρn^2 = constant. Assuming a ground speed of 1,200 r.p.m. on

* Advisory Committee for Aeronautics, I.C.E. 121.

full throttle, the speeds of revolution corresponding to constant efficiency at various altitudes are given in the second line of Table 21.

TABLE 21.

Altitude in feet ...	0	5000	10000	1500	20000	25000	30000
Airscrew R.P.M. ...	1200	1300	1410	1526	1650	1810	1990
Engine Brake M.E.P. lbs. per sq. inch :—							
Normal Engine ...	108	92	77	61	51	40	31
Constant Power to 10,000ft.	108	109	110	89	73	58	46
Constant Power to 30,000ft.	108	109	110	110	110	109	108

In order to maintain the relationship ρn^2 = constant, the applied torque, and therefore the brake mean effective pressure of the engine, must be constant over the speed range indicated.

The variation in brake mean effective pressure with speed differs widely in different engines, being dependent upon cylinder design and particularly upon valve size and disposition. An examination of a considerable number of aero engine power curves shows that on full throttle the variation of torque with r.p.m. over the working range of speed varies from 5 per cent. to 15 per cent. of the mean torque. In certain engines the variation is, however, considerably lower than this. In an experimental engine tested by the Author the brake mean effective pressure developed at various airscrew speeds was as indicated in the last line of Table 21. The figures given show the variation in torque with speed in this case to be only 1 per cent. of the mean torque over a speed range from 1,200 to 2,000 r.p.m. If such an engine were capable of constant power development at all altitudes, ρn^2, and therefore the airscrew efficiency, would be sensibly constant.

The variation in brake m.e.p. with altitude if the power were maintained constant up to 10,000 feet is shown in line 4 of Table 21, while the figures given in line 3 refer to the normal engine.

In the normal aeroplane power plant the airscrew is designed to give the highest overall efficiency under the average conditions of flight. The figures given in Table 21 show that with a suitable speed characteristic the constant power engine enables the maximum overall efficiency of the aeroplane to be more nearly approached than does the normal engine. While this is so, it is to be realised that for the same maximum power the constant power engine gives the machine a much wider range of flying speeds than the normal engine. If the full range of flying speeds is demanded, the constant power engine will evidently necessitate the use of a variable pitch propeller or some such device as will maintain the speed within the limits for which the engine is designed.

(19.) Aeroplane Performance with Constant Power Unit.

In the normal aero engine cylinder of the usual stroke bore ratio the maximum possible compression ratio is dependent upon cylinder head and piston design as effecting the minimum permissible clearance volume. In all present-day aero engines a maximum compression ratio between 6.5 and 7.5 to 1 is readily obtainable by the use of high-compression pistons, and where the sparking plugs are located in the head, ratios higher than this are quite practicable. The tests discussed indicate the possibility of maintaining constant power from the ground up to a height of approximately 10,000 feet with a maximum compression ratio between 6 and 7 to 1. Assuming that this represents the practicable limit to

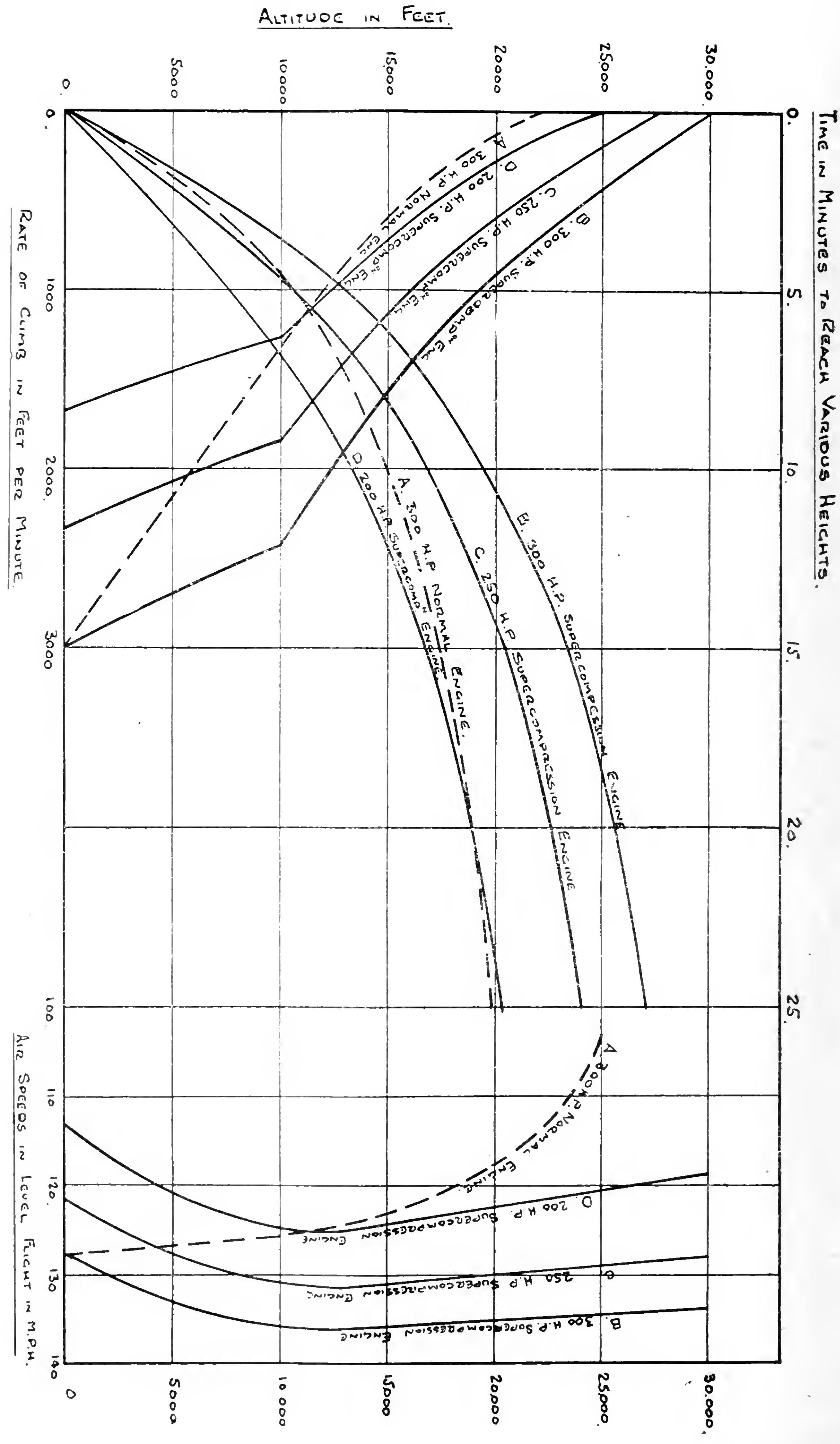

Altitude in Feet.
Time in Minutes to Reach Various Heights.
Rate of Climb in Feet per Minute.
Air Speeds in Level Flight in M.P.H.
A. 300 H.P. Normal Engine.
B. 300 H.P. Supercompression Engine.
C. 250 H.P. Supercompression Engine.
D. 200 H.P. Supercompression Engine.

Fig. 14.

the use of high compression, the curves of Fig. 14 have been prepared to show the probable performance of the aeroplane exemplified in para. (13) with various engines. The curves shown in Fig. 14 refer to the following conditions :—

CURVES A.—Normal engine developing 300 b.h.p. on the ground.
CURVES B.—Engine of 300 b.h.p. developing constant power up to 10,000ft.
CURVES C.—Engine of 250 b.h.p. developing constant power up to 10,000ft.
CURVES D.—Engine of 200 b.h.p. developing constant power up to 10,000ft.

In each case a constant airscrew efficiency of 80 per cent. has been assumed, and the speed of climb has been taken as 75 m.p.h. near the ground, increasing with increasing height in accordance with the relationship ρV^2 = constant.

From the plotted results it will be seen that with the 200 b.h.p. power recuperating engine the ceiling height is somewhat greater than with the 300 b.h.p. normal engine, while the time taken to reach the ceiling height is nearly the same in each case. This is due to the fact that while the rate of climb up to approximately 10,000 feet is lower with the former than with the latter, it decreases less rapidly, due to the maintenance of constant power up to 10,000 feet, and to the fact that at altitudes above 10,000 feet the high-compression engine is affected to a lesser degree by reduction in density than the normal engine.

Assuming that engine weight is directly proportional to the maximum b.h.p. developed, the saving in weight is seen to be approximately 30 per cent.

Comparing curves *A* and *B* it will be observed that the maintenance of constant power in the 300 h.p. engine up to a height of 10,000 feet, increases the ceiling of the machine by approximately 36 per cent. as compared with the normal 300 b.h.p. engine. The maximum speed of the aeroplane in level flight at various altitudes with the two engines is as follows :—

TABLE 22.

Altitude in feet	5,000	10,000	15,000	20,000	25,000
300 h.p. normal engine	127	126	123	118	—
300 h.p. power recuperating engine	133	136	136	135	135

The increased air speed, together with the increased rate of climb and the improved ceiling of the aeroplane obtainable with the power recuperating engine, indicates clearly the possibilities of such an engine, particularly as applied to military and long-distance commercial craft.

(20.) Conclusions.

The investigation leads to the following general conclusions :—

(*a*) The performance of an aero engine under the conditions obtaining in flight, as measured by the rate of decrease of power, and the variation in fuel consumption, with diminishing density, is dependent upon engine type and cylinder design. The factors which limit the power output and thermal efficiency of an engine have a relatively greater effect at altitude than on the ground.

(*b*) In the aero engine, a high degree of compression is essential. The rate of decrease in power with decrease in density, and the petrol consumption per unit of power, decrease with increase in compression ratio.

(*c*) The tests results given establish the possibility of super-compression as a means of power recuperation at altitude. In the super-compression engine, constant power is maintained without undue complication of mechanism, and with

no sensible increase in engine weight. The data discussed points to the superiority of air cooling as against water cooling in a power recuperating unit.

The Author takes this opportunity of expressing his indebtedness to the Director of Research of the Air Ministry for permission to publish the experimental results upon which the above discussion has been based, and to Professor A. H. Gibson, D.Sc., M.I.C.E., M.I.Mech.E., of Victoria University, Manchester, for his kindness in allowing the Author to refer to much of his published and unpublished work.

REVIEWS

The Case-Hardening of Steel. By Harry Brearley. (Longmans, Green & Co.) 16/- net.

The Author is to be congratulated upon the second edition of this very useful book. The various chapters will be found to constitute a reliable guide in practice for those interested industrially in the art of case-hardening. The theoretical principles are well explained, but what is almost more important is the general handling of the subject from the practical point of view. The illustrations are numerous and well chosen with a view to illustrating the various points dealt with in the text.

The book is divided into eleven chapters, each dealing with some different aspect of case-hardening. Chapter II., dealing with the structural changes, is well done and should be very carefully studied. Chapter X., dealing with hardening and tempering of steel, is also very well done, and contains many observations which are the result of practice and, no doubt, costly experience at one time or another. In Chapter IX. the Author deals with the various steels available for automobile construction, and the addition to this edition will no doubt be welcomed. It is surprising that in dealing with automobile steels the Author has not seen fit to include the 12/14 per cent. chromium steel which is so valuable for its rust and stain resisting properties and for which there must surely be a considerable future in the automobile and aero industry.

W. H. H.

Aeroplane Performance Calculations. Harris Booth. (Chapman & Hall, D.U. Technical Series.) 21/-.

In common with most engineering calculations, the estimation of the performance of an aeroplane involves assumptions of doubtful accuracy. The doubts arise from two causes: (1) absence of the precise experimental results required, (2) conflict among such experimental results as bear upon the point. In his endeavour to live up to the title of the series in which his book is published, Mr. Booth refrains not only from indicating where the doubts lie, but also from discriminating between the two varieties. He makes amends by definite statements (*e.g.*, pp. 4, 96, 97), but omits to give references which might enable the intelligent reader to check them. Such a course may be "directly useful," but it cannot fail to leave an unhappy impression on the reader who has any previous knowledge of the subject. To this extent the sufferer is Mr. Booth, though no small part of the real responsibility lies on the inventor of the pernicious title of this "directly useful" series.

But another class of reader will not escape unharmed—the draughtsman anxious to improve his standing in his profession. For his sake, since this and other similar books make a special appeal to him, the warning must be given that only an expert can discriminate between what is good in the book and what is untrustworthy.

A large part of the book is, in effect, an elaborate sliderule. No errors of consequence have been detected, and where the reader is attracted by any of the methods described, he can safely use the graphical or tabular schemes suggested. One cannot refrain, however, from expressing the opinion that tabulation is not an exact science, and what appeals to Mr. Booth as *the* way may not impress another. Few things are harder to grasp than another man's tabular work.

Some technical points require remark. The method recommended (p. 9) for dealing with an unknown body—to take the nearest "perfect" shape and add cockpits and windscreens at so many pounds each—is unlikely to yield good results. Tailplanes are dealt with as if they were merely, say, fins, regardless of the fact that, owing to downwash, a tailplane may have, and often does have, a negative resistance. The three-page treatment of wing characteristics is hardly commensurate with the importance of the subject.

The whole treatment of engine power is very confusing, and the precise difference between P_r (engine power at full revolutions) and P_t (engine power at full torque) is nowhere made clear. The assumption that friction power/indicated power=.262 for rotary engines and .161 for stationary engines, without a word of explanation or reference, is typical of the book.

The get-up of the book is excellent, the type and paper good, and a model index is provided.

THE

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All communications should be addressed to the Editor.

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Notices of the Royal Aëronautical Society.

Lectures.

In addition to the lectures announced last month, the programme for the next Session has now been completed by the addition of the following papers:—

Oct. 6.—"Some Notes on Aeroplanes in Tropical Countries," Air Commodore H. R. M. Brooke-Popham.

Oct. 20.—"The Langley Machine and the Hammondsport Trials," Mr. Griffith Brewer.

Donations.

The Council desire to thank the British Aeroplane Company for their kind donation of a set of slides of the Bristol Ten-Seater Commercial Aeroplane for the Society's loan collection of lantern slides.

Aeroplane Camera.

An inquiry has been received for an aeroplane camera which is wanted for experimental purposes. Any member who may have a suitable camera for disposal should communicate with Dr. E. P. Farrow, Limehurst, Spalding.

Scottish Branch.

Details of the following arrangements have been received from the Honorary Secretary of the Scottish Branch:—

Sept. 19th.—Annual Meeting. The Right Hon. Lord Weir, LL.D., in the chair.

The proposed arrangements for Sir Keith and Sir Ross Smith's Cinema Travelogue in Hengler's Circus, Sauchiehall Street, on their "Flight to Australia," are as follows:—

Oct. 3rd.—Proposed luncheon by the Lord Provost and Magistrates, when the Lord Provost and Magistrates will be invited to the evening lecture.
Oct. 4th.—Dinner by the Royal Aëronautical Society at 6 p.m. Lecture under the auspices of the Society.
Oct. 5th.—Lecture under the auspices of the Glasgow Education Authority.
Oct. 6th.—Lecture under the auspices of the Royal Philosophical Society.
Oct. 7th.—Lecture under the auspices of the Royal Institute of Engineers and Shipbuilders.
Oct. 8th.—Students' and Boys' Brigade Officers' night.

LECTURE PROGRAMME.

Oct. 17th.—Lecture by Colonel V. C. Richmond (of the Airship Department, Directorate of Research, Air Ministry), on "The Organisation of a Colonial Airship Service," in the Engineering Class-Room of the University, at 8 p.m. *Chairman*—Lord Invernairn.

Oct. 31st.—Lecture by Professor Gordon Gray, D.Sc., of Glasgow University, on "Research Work on the Application of Gyroscopes to Aviation, with Solutions of the Problem of the True Vertical on Moving Vehicles," in the Natural Philosophy Class-Room of the University, at 8 p.m. *Chairman*—Mr. James Weir, C.M.G.

Nov. 14th.—Lecture by Major-General Sir Hugh Trenchard, Bt., K.C.B., C.B., Chief of Air Staff, on "The Auxiliary Air Force," in the Large Hall of the Institute of Shipbuilders and Engineers, Elmbank Crescent, at 8 p.m. *Chairman*—The Right Hon. Lord Weir, P.C., LL.D.

Dec. 12th.—Lecture by Colonel Gold, of the Meteorological Dept., Air Ministry, on "The Application of Meteorology to Aviation," in the Royal Technical College, George Street, at 8 p.m. *Chairman*—Sir John Hunter, K.B.E.

1922.

Jan. 23rd.—Lecture by Brig.-General R. K. Bagnall Wild, C.M.G., C.B.E., Director of Inspection, Air Ministry, on "Installation," in the Royal Technical College, George Street, at 8 p.m. *Chairman*—Sir John Reid, D.L.

Feb. 11th.—Lecture by Mr. H. Ricardo, A.M.Inst.C.E., on "Some Problems connected with Engines for High Altitude," in the Engineers' Class-Room of the University, at 8 p.m. *Chairman*—Professor Mellanby, D.Sc.

Feb. 25th.—Lecture by Mr. Allan E. L. Chorlton (Air Expert of Messrs. Beardmore, Ltd., London), on "Special Light Weight Engines." *Chairman*—Mr. Harold E. Yarrow, C.B.E.

Mar. 11th.—Lecture by Professor L. Bairstow, F.R.S., C.B.E., Professor of Aeronautics in the Imperial College, London, on "Natural Flight Instincts of some Modern Aeroplanes," in the Engineers' Class-Room of the University, at 8 p.m. *Chairman*—Professor Cormack, D.Sc.

Mar. 18th.—Lecture by Colonel Lockwood Marsh, O.B.E., LL.B., Secretary of the Royal Aëronautical Society, on "Some Side Lights on the History of Aeronautics," in the Royal Technical College, George Street, at 8 p.m. *Chairman*—Ex-Professor Barr, LL.D.

W. LOCKWOOD MARSH, *Secretary*.

R38.

August 24th, 1921.

The disaster to R38 is, without exception, the greatest single catastrophe in the history of aeronautics. The members of this Society who perished therein are commemorated elsewhere in this issue of the Journal, but it is felt that the names of all who lost their lives should be recorded here. The relatives of each and all of them may rest assured that we mourn with them. It is perhaps not unfitting to express the hope that this disaster may not retard the future development of airships. It would be lamentable indeed were their sacrifice allowed to prove vain.

British Officers.

Air Commodore E. M. Maitland, C.M.G., D.S.O., A.F.C.
Flight Lieutenant J. E. M. Pritchard, O.B.E., A.F.C. (Air Ministry Representative).
Flight Lieutenant G. M. Thomas, D.F.C.
Flight Lieutenant I. C. Little, A.F.C.
Flight Lieutenant R. S. Montagu, D.S.C. (Navigator).
Flying Officer V. H. Wicks.
Flying Officer T. F. Matthewson, A.F.C. (Engineer Officer).

National Physical Laboratory Representatives.

Messrs. J. R. Pannell and C. W. Duffield.

Royal Airship Works, Cardington, Representatives.

Mr. C. I. R. Campbell, Superintendent, and Mr. F. Warren.

British—Other Ranks.

Flight Sergt. S. J. Heath.
,, ,, W. H. Greenel.
,, ,, H. Thompson.
,, ,, F. Smith.
,, ,, J. Rye.
,, ,, A. T. Martin.
Sergeant J. W. Mason.
,, F. E. Burton.
L.A.C. G. S. Anger.
L.A.C. W. Oliver.
L.A.C. J. N. Willson.
A.C.1 J. O. Drew.
A.C.1 C. W. Donald.
A.C.1 C. W. Penson.
A.C.1 E. E. Steere.
A.C.2 R. Parker.
A.C.2 R. Withington.

American Officers.

Commander L. A. H. Maxfield, U.S.N.
Lieutenant Commander W. N. Bieg, U.S.N.
Lieutenant Commander E. W. Coil, U.S.N.
Lieutenant H. W. Hoyt, U.S.N.
Lieutenant C. G. Little, U.S.N.
Lieutenant M. H. Esterly, U.S.N.

Americans—Other Naval Ranks.

C.M.M. L. E. Crowl.
C.M.M. A. L. Loftin.
C.M.M. W. A. Julius.
C.M.M. G. Welch.
C.B.M. C. J. Aller.
C.M.M. J. T. Hancock.
C.B.M. M. Lay.
C.M.M. R. M. Coons.
C.M.M. W. J. Steele.
C.B.M. A. D. Pettit.

Per Ardua ad Astra.

Obituary.

AIR COMMODORE E. M. MAITLAND, C.M.G., D.S.O., A.F.C., A.F.R.Aë.S.

Edward Maitland Maitland was born in 1880, the elder of two sons—of whom the younger, Harry, died in hospital during the war—of the late Arthur Maitland, Barrister-at-law, of Shudy Camps Park, Cambridgeshire. He was educated at Haileybury College and Trinity College, Cambridge, after which he came to London to read for the Bar. He, however, volunteered for service in South Africa, and on returning home received a permanent commission in the Essex Regiment. He took up ballooning about 1907 and received most of his early training from the late A. E. Gaudron, with whom and Mr. C. C. Turner he made a "record" balloon voyage from England to Russia in November, 1908, a distance of 1,117 miles being covered. Thereafter Maitland became one of the most ardent balloonists in this country, and, when he could be persuaded to relate his experiences, had a wonderful fund of anecdotes of adventures in balloons. His first parachute descent was made at the Alexandra Palace in 1908. In 1910 he purchased a Howard-Wright biplane, on which he proceeded to teach himself to fly, being one of the competitors at the Doncaster Aviation Meeting of 1910. This machine was subsequently purchased by the War Office, and he was very proud of the fact that it was the first aeroplane acquired by the British military authorities. Early in 1911 he had a bad crash in an aeroplane, in which both his ankles were broken, which necessitated a prolonged stay in hospital. On recovery he was, somewhat to his disappointment at the time, posted to No. 1 (Airship) Company of the Air Battalion at Aldershot, as he was not yet considered fit to fly an aeroplane. He would often refer, in later life, to the curiously fortuitous circumstances of his original connection with airships, of which he was to become the most devoted adherent and ardent exponent. His aeronaut's (balloon) certificate was numbered 13 and dated November 22, 1910, which was followed by his taking the British airship pilot's certificate No. 8 on September 19, 1911; while, although he first started flying aeroplanes much earlier, he did not take his aeroplane brevet until April 4, 1913, going to the Farman School at Etampes for the purpose and receiving French certificate No. 1, 281. On January 1, 1914, when the Army authorities ceased experimenting with airships, Maitland transferred as a Squadron Commander to the Naval Wing of the Royal Flying Corps, being then the senior Army airship officer, and became second-in-command to Commander E. A. D. Masterman, of the Naval Airship Service. Shortly prior to this, on October 18, 1913, he carried out the first parachute descent from an airship, the Beta, in flight. In the early summer of 1914 he went to Bitterfeld in Germany to watch the construction of a Parseval which had been ordered, but was never delivered, for the Navy. He only just succeeded in getting back to this country before war broke out, and almost immediately proceeded to Belgium and was chiefly instrumental in organising the balloon detachment which operated from Firminy; finally taking out the Beta in November, 1914. During this period Maitland became imbued with the importance of the kite-balloon, as used by the Germans and Belgians, and there is in the archives of the Admiralty his despatch which was the cause of the adoption of this weapon by the Royal Naval Air Service. It was therefore inevitable that he should be appointed to command the Kite-Balloon Training Station at Roehampton when this was commissioned in March, 1915. He remained there until the spring of 1916, during which time he carried out much experimental work, regardless of personal danger, including the first voluntary free run in a kite-balloon, to ascertain the effect of cable breakage, and an experimental parachute descent from a height of 10,000 feet. From Roe-

hampton he came to take charge of the Operations Section of the Air Department, Admiralty, but only remained there for a few months as his health would not stand unaccustomed office work. In the autumn of 1916 he was appointed commanding officer to commission Pulham, the first rigid airship station to be completed in this country. He was recalled from there to the Admiralty again in June, 1917, to take up the responsible duties of Captain Superintendent, Lighter than Air, in the Air Department. In November, 1917, he assumed the title of Superintendent of Airships when the Airship Section of the Air Department became the Airship Department, Admiralty, on the transfer of aeroplanes and seaplanes to the Air Board. This position he held until the signing of the Armistice, and for some time thereafter, and it was almost entirely due to the effect of his personality that the Board of Admiralty embarked upon a greatly increased programme of airship construction, which included twelve rigid airships and a large number of the non-rigid type. When airships were transferred to the Air Ministry at the end of 1919 he went to Kingsway in a somewhat indefinite appointment to assist in fitting the various portions of the Airship Department into the appropriate departments of the Air Ministry organisation. At the time of his death he was Commanding Officer of Howden Airship Base.

Though it is not possible to detail his many parachute descents here, it must not be forgotten that during all the period from 1916 onwards he took any and every opportunity of jumping off in a parachute from every type of aircraft—balloon, kite-balloon, airship and aeroplane—for no other reason than to give others a lead and prove to the authorities and the public that the parachute offers a means of saving life in case of accident. In view of this it is peculiarly significant that when found after the accident to R38 he was shown to have devoted his last moments to an endeavour to check the fall of the airship rather than to saving his life by means of a parachute.

It is impossible to write adequately of Maitland's personal charm of appearance, voice and character. Everyone who met him received the impression —which every action of his did nothing but confirm—of absolute honesty of purpose, combined with an unflinching devotion to the cause of airships. He imbued those who served with him with a sense of trust which was absolute, while the personal love which he inspired in all with whom he came in contact was truly wonderful. He had tact to a quite exceptional degree, and his manners recalled the courtly grace of a bygone age. To all those who knew him he will live as an unforgettable memory. He was a firm supporter of this Society, being elected as a Founder Member in April, 1909, and made an Associate Fellow in 1912. He served on the Council from March, 1912, to November, 1913. Many members will remember the delight which he gave to an audience of children, when he related his experiences during the Atlantic flight of R34 at the Society's Annual Juvenile Lecture in January, 1921, whilst his last opportunity of manifesting his interest in the Society was in very appropriately taking the chair on the occasion of Major Orde Lee's paper on "Parachutes" and Mr. Dyer's "Airship Fabrics" lecture on March 3 this year.

CONSTRUCTOR COMMANDER C. I. R. CAMPBELL, O.B.E., M.I.N.A., F.R.Aë.S., R.C.N.C.

Charles Ivor Rae Campbell was educated between the years 1894 and 1899 at the Royal Naval Engineering College, Devonport, where he obtained the Newman Memorial Prize for highest proficiency in engineering subjects. From there he went in 1899 to the Royal Naval College, Greenwich, where his career was remarkable, in that he followed the engineering course by taking also the course in design for constructors; thus obtaining very exceptional qualifications for his future career. On leaving Greenwich he went to the Admiralty, where

he remained until 1908, engaged chiefly upon submarine design work. He was then appointed overseer for submarine hulls at Messrs. Vickers' Works at Barrow-in-Furness, where he remained four years, during which period he laid the foundation of his future airship work through being able to watch the construction of Naval Airship No. 1, the first British rigid airship, which was built at Barrow while he was there. From Barrow he was appointed, in 1913, Admiralty overseer at Messrs. Armstrong's works at Newcastle-on-Tyne for the construction of H.M.S. Malaya and various submarines, where he remained until December, 1914, when he sailed for America as Admiralty overseer of the construction of submarines and M.L. boats in the United States. He also went to Canada, where he supervised the erection and testing of these boats before returning to England to undertake airship design work under Mr. A. W. Johns, in the Department of Naval Construction at the Admiralty, at the end of 1915; being immediately responsible for the work of the airship design staff then formed.

It was soon after this that he produced the design of the "23X" class of rigid airship. The design, of which only R27 and R29 were built, was approved in spite of considerable opposition owing to the absence of a structural keel, there being merely a corridor through the hull which was not a strength member. In 1917, on the reorganisation of airship work in the Admiralty, he assumed the primary responsibility for airship design by taking charge of the Design Section of the department of the Director of Production (Airships) under the Navy Controller. It was during this period that the design of R38, which incorporated many original features, was prepared. On leaving the Admiralty in 1920 for the Air Ministry, he became Superintendent of Airship Construction and Design at the Royal Airship Works, Cardington.

Campbell was unquestionably the most experienced and foremost airship designer in this country, and had, outside Germany, a unique knowledge of the problems of rigid airship design and construction. He had the fullest confidence in the future of airships, and was a firm believer in the importance of progressive increase in size. For the head of a department he assumed an unusual amount of personal responsibility for the work, and was never content to leave the smallest detail to others. He was always particularly anxious to study the results of his work in practical flight, and had been on all the trial flights of R38, and had succeeded in obtaining the somewhat reluctant permission of his superiors to his embarking in the airship when she should leave for America.

He had done much proselytising work to arouse both technical and public interest in airships, among the lectures he gave being one before the Institute of Naval Architects on "The Development of Airship Construction," on April 10th, 1919. He was elected an Associate Fellow of the Society on March 16th, 1920, which was followed by his election to Fellowship on April 19th this year. On April 25th last, at the request of the Society, he read a Paper on "Airship Transport," at the Olympia Efficiency Exhibition.

FLIGHT LIEUTENANT J. E. M. PRITCHARD, O.B.E., A.F.C., F.G.S., A.F.R.Aë.S.

John Edward Maddock Pritchard was born at Leighton Buzzard in 1889, and was of Welsh ancestry. He was educated privately and at Trinity College, Cambridge, whence he proceeded to the Royal School of Mining, South Kensington, where he graduated First Class in mining surveying. He then took up the career of a mining engineer, and was at one time engaged upon one of the most important mining surveys ever carried out in this country, having been elected a Fellow of the Geological Society of London some time previously. His interest in aeronautics was not confined to his war experience, as he had made several flights in the early days of aviation with, amongst others, the late S. F. Cody.

He joined the Royal Naval Air Service as a Flight Sub-Lieutenant on May 24th, 1915, and took a preliminary course in balloon piloting and aerostatics at the Kite Balloon Training Station at Roehampton. From there he proceeded to Kingsnorth R.N. Airship Station, in August of the same year, from where he was posted to Polegate as captain of an S.S. airship. He remained at Polegate until April, 1916, when he was sent out to the airship station at Mudros, where anti-submarine patrols were carried out in conjunction with the Allied Fleets. While in the Mediterranean Pritchard contracted dysentery, and was ordered home in consequence, being posted on his return again to Polegate as Senior Flying Officer. He was promoted Flight Lieutenant at the end of 1916, and in the following year took command of a coastal type airship (C24) at East Fortune. He subsequently was captain of a Parseval airship (P6) at Howden, where he achieved the reputation of being one of the most capable and scientific pilots in the airship service. On the formation of the Airship Department at the Admiralty, Pritchard was appointed, in September, 1917, to the staff, where he was responsible for the maintenance of and supply of spare parts for rigid airships, and also became acceptance pilot of rigid airships as these were taken over from the constructors by the Superintendent of Airships, representing the flying side of the service. On the formation of the Royal Air Force, on April 1st, 1918, he was appointed acting Major (S.O.2), having been promoted Flight Commander in the previous January. From then onwards perhaps his most important work, apart from his acceptance duties, was his collaboration with the Air Intelligence Department of Home Forces G.H.Q., at Whitehall, in extracting, from the information obtained during and after Zeppelin raids in this country, technical data of incalculable value as to the development of airship design and practice in Germany. In the course of this work he examined several batches of Zeppelin crews, on one occasion visiting France for the purpose of interrogating the crew of L49, and assisted in the translation of innumerable log-books and other documents which proved a mine of information, which was embodied in a series of reports the importance of which it is impossible to overestimate. As the natural outcome of this experience, Pritchard was sent to Germany in December, 1918, as technical airship officer under Admiral Browning on the British Naval Section of the Inter-Allied Armistice Commission. He returned with a mass of further information, which he made available to others in his usual clear and concise manner. In July, 1919, Pritchard represented the Air Ministry on the Atlantic flight of R34, and on the arrival of the airship over the landing field at Long Island volunteered to land by parachute in order to take charge of the ground landing party in the absence of Major Fuller, who had proceeded to another emergency landing ground where it had been thought that R34 would be compelled to land through shortage of petrol. Since October 22nd, 1919, Pritchard had been in the Lighter-than-Air Section of the Air Ministry Research Department as acceptance pilot, receiving a short service commission as Flight Lieutenant on January 8th, 1920.

As a pilot he combined to an unusual extent flying ability with scientific knowledge, which made him one of the most valuable members of the airship service. He was particularly notable for tracing to its source any unusual phenomenon which might occur during the flight of an airship and for his grasp of the lines of development required for the improvement of airships. It may be said of all his work that he laboured indefatigably for the good of the airship service in general and was always anxious to make available for all any knowledge which he obtained. He was of an unusually attractive disposition; never too busy to give assistance or advice, always cheery, and a most amusing and enlivening companion.

Pritchard was elected an Associate Fellow of the Society on February 17th, 1920, and was a member of the Candidates and Library and Publications Committees. He lectured before the members on "Rigid Airships and Their Development" on February 4th, 1920.

J. R. PANNELL, A.M.I.M.E., F.R.Aë.S.

John Robert Pannell received his technical education at the Northampton Institute, where he was awarded a diploma, after which he went through the shops of Messrs. Bruce Peebles, Edinburgh. He went to the National Physical Laboratory as a student assistant in the engineering department, in 1906, and was first employed in aiding Mr. Jakeman, who was conducting experiments on the specific heat of steam. After two years as a student, he was taken on to the Laboratory staff as a junior assistant, and helped Dr. T. E. Stanton in work on the strength and fatigue of welded joints, the results of which were published in their joint names in 1912. He then pursued a lengthy series of researches on the friction of fluid flow in pipes and the rate of heat transference from fluids flowing through pipes, and established experimentally the law of dynamic similarity for pipes by comparing the results obtained with air, water and oils. A joint Paper of Pannell's with Dr. Stanton was published in Vol. 214 of the "Philosophical Transactions of the Royal Society," at page 199, on "Similarity of Motion in Relation to the Surface Friction of Fluids." In 1914 he was transferred to the Aeronautics Department (then a branch of the Engineering Department) of the Laboratory, and since that date had been continuously employed there. His early aerodynamical work covered a wide field, among the subjects on which he was engaged being a systematic research on biplane systems; whilst he carried out tests on the model of the original Handley Page aeroplane. Later on during the war he took up the subject of resistance of bombs, and did much valuable work, in conjunction with Mr. N. R. Campbell, towards improving the technique of the measurement of resistance of stream-line bodies. This naturally led him to the subject of airships, with which he was almost exclusively concerned from 1917 onwards.

In this work on airship research Pannell was always very fully alive to the necessity of corroborating the results of his research work on models by measurements obtained in actual airships in flight, and was most emphatic in urging the importance of at least one airship being permanently detailed for this purpose, in order that research work might not be thrown back by the constant delays owing to airships being diverted to other work. He organised a very complete system of experiments from this point of view, and had made many experimental flights, notably in R33 and R36, as a result of which he collected a mass of most valuable data, often under most trying conditions. It would be impossible to overestimate the value of the work he did in this direction, which was carried out with characteristic enthusiasm and thoroughness, frequently at great personal inconvenience. At the time of his death he had practically completed a comparison of resistance of a stream-line shape in air and water, and was also engaged upon an investigation into the effect of surface roughness on airship resistance. It would be impossible to find a more enthusiastic believer in the commercial value of airships, in which he had great confidence, or a more ardent worker in the cause of airship development.

Pannell was elected an Associate Fellow of the Society on April 19th, 1917, and a Fellow on July 5th, 1918. He was a member of the Sub-Committee on Symbols of the Technical Terms Committee, 1919, and in 1917 read a Paper to members on "The Wind Channel: Its Design and Use."

LIEUTENANT C. G. LITTLE, U.S.N.R.F.

Lieutenant Charles G. Little was born at Newburyport, Massachusetts, in 1895, and entered the United States Service of Naval Aviation on May 9th, 1917, as an Ensign, being promoted Lieutenant "J.G." in 1918, and full Lieutenant later in the same year. He was one of the American Naval Aviation officers who

came over to Europe as airship pilots during the war, being stationed at Paimbœuf Air Station in France, and held the French airship pilot's brevet, No. 97. He was awarded the U.S. Navy Cross for his services. Lieutenant Little joined the Society as a Foreign Member on October 19th, 1920.

LIEUTENANT-GENERAL SIR DAVID HENDERSON, K.C.B., K.C.V.O., D.S.O., Hon.F.R.Aë.S.

"David" has gone, and the world of aviation laments the departure of one of its most interesting and greatest figures.

David Henderson started life as an engineer, but opportunity offered and he transferred his activities to the more honourable and less lucrative profession of arms. His career as a soldier was conspicuously successful, and when aviation first appeared on the military horizon, he had a long and distinguished record of active service to his credit. His greatest successes had been won in the Intelligence Branch of the General Staff—and it was this experience which qualified him particularly to grasp the vast possibilities of aircraft as a means of reconnaissance when his military and naval contemporaries were both sceptical and inert in their attitude towards this new weapon of war.

In 1912 he stepped into the aeronautical world by "taking his ticket" at Brooklands at the age of 50, to the furtive annoyance of some of his equals and to the amazement and admiration of his juniors; at the time he must have been the oldest man in the world who had attained this qualification. General Henderson was then Director of Military Training in the War Office, and it was probably the fact that he was the only senior officer in the Army who could fly, which led to military aviation being placed under a branch of his particular directorate.

From that moment his whole life was devoted to the new cause. No one who did not actually work under him can realise the vast amount of time and energy he gave to aviation during 1912 and 1913. The onerous duties of Director of the Training of the Army already more than fully occupied his time, but he spent untold hours both by day and night in tackling the endless and difficult questions which arose during the birth and development of the Royal Flying Corps and the Military Aeronautics Directorate. His foresight and judgment at this time were remarkable; if the archives of the War Office dealing with aviation at this period are ever seriously studied, they will be a revelation of his sound judgment combined with imagination and enthusiasm. Every step taken was considered fully and thoroughly, and the fruits of almost every decision of importance have endured to the present day through all the changes of control and of headquarter organisation which have occurred since. To him must be given the credit of the first conception of a flying service common to both Army and Navy, divided into Military and Naval Wings and controlled by an Air Committee, consisting of the leading officials in the Government and in the two great warlike departments concerned with aviation. This Committee had operated with great success for two years when the war started; if it could only have been continued with increased powers, much useless and pernicious overlapping and competition between the Admiralty and War Office could have been avoided. But David Henderson and some of the other members went off to the war, and the Committee was allowed to lapse, until the two Air Boards and eventually the Air Ministry restored the policy of central control over all matters concerned with aviation. For the first year of the war General Henderson commanded the Royal Flying Corps in the field with conspicuous distinction; Lord French, the Commander-in-Chief, was lavish in his praise of the good work he did, and it was under him that the Royal Flying Corps created a reputation for dash, courage, good discipline and reliability in battle, which was maintained in face of all difficulties until the last day of the war.

In the middle of 1915 David Henderson returned to the War Office and again took up the duties of Director-General of Military Aeronautics and Aviation Member of the Army Council, the post which he held before the war, and continued in this capacity until the autumn of 1917. During this period the Military Aeronautics Directorate and the Royal Flying Corps grew both in size and in accomplishment far beyond the dreams of the saner enthusiasts at the beginning of the great struggle. His counsels on the first Air Board under Lord Curzon in 1916 and the second Air Board under Lord Cowdray in 1917 were of infinite value, and were a potent factor in the steady development towards the creation of the Royal Air Force under an independent Air Ministry. By the frankness of his statements and his almost furious opposition to the machinations of self-seekers and self-advertisers, he earned for himself a not inconsiderable group of enemies and detractors, by whose instigation various criticisms were levelled at him in Parliament, in the Press and in private. They carried no weight, however, with those who really knew him, and in the Pemberton-Billing inquiry, held by the Government in 1916, he absolutely vindicated his policy on every debatable point, and established a reputation for clear-mindedness and ability in legal debate such as has seldom been attained before by a simple soldier.

In the autumn of 1917 it was decided to create an independent Air Ministry, and General Henderson was relieved of his appointment as D.G.M.A. and Member of the Army Council to collaborate with General Smuts and advise the War Cabinet as to the best lines of development and organisation.

In January, 1918, the Air Ministry came into being, and General Henderson was appointed a member of the Air Council.

Then came perhaps the worst moment in the whole history of the development of the flying services of this country. Lord Rothermere had been appointed as the first Air Minister; his inexperience in the workings of a Government Department and the difficulties of control of an entirely new and far from homogeneous service, led to serious differences of opinion between him and the Chief of the Air Staff, General Trenchard. The latter thought it his duty to resign, but this fact was not disclosed until a month afterwards, in March, 1918, when Lord Rothermere announced the fact and nominated his successor without consulting the Members of the Air Council.

General Henderson rose in righteous indignation and objected vehemently to the course adopted by the Air Minister and to his selection, and finally resigned as a protest against the policy pursued.

Very soon afterwards Lord Rothermere was forced to resign himself, owing to the difficulties of the situation he had created, but unfortunately David Henderson had gone, and never again took any active participation in the control of the Royal Air Force.

His departure was a great and irreparable loss to the young service, and the rectitude of his action during the crisis has been fully vindicated by subsequent events.

In the summer of 1918 he suffered a cruel blow from the death of his gallant son Ian, in an aeroplane accident in Scotland.

After his resignation from the Air Council, General Henderson served with distinction under the War Office for the few remaining months of the war, and then took over the control of the International Red Cross organisation at Geneva. But a reserved and highly sensitive temperament had been severely taxed by unremitting hard work in the service of his country for many years, and the resulting wear and tear, combined with the effects of his son's tragic death, must have undermined his health and cut short his career of usefulness and good service to the British Empire and to humanity at large.

David Henderson was a natural soldier, a great gentleman and a good Scotsman; a fighting enemy and an unflinching friend. He combined great ambition with devotion to duty, and fierce courage with gentleness and an exceeding kind heart. His fine spirit was remarkable, even amongst the most gallant of the old

Army; a quality which unfortunately gave him the power to undermine his health by overwork in the cause of aviation.

He was a delightful companion and a gifted raconteur. His subtle wit and imperturbable charm of manner captivated all those who came into contact with him, and his friends and admirers were legion. His scientific and engineering knowledge was remarkable for a soldier, and the Committee of Aeronautical Research owe much to his advice in the early days. He had great artistic talent and was a devoted lover of music.

Although he was a great soldier, he might well have been an even greater diplomat if Fate had led his steps into that walk of life; he was cautious in council and slow in deliberation, always manœuvring round a difficulty if it were humanly possible; but once it was clear that further consideration was useless, his action was swift, decisive and far-reaching.

Let us mourn seriously and sincerely for David Henderson; the rising generation does not promise to produce more men of his stamp and quality for the service of aviation. He has left us, but his works will live and grow and multiply; and the Air Force of the future should look back to him as their real Creator and their first Chief.

He had been an Associate Fellow of the Society since 1912, and was elected Honorary Fellow on December 14th, 1917.

SQUADRON LEADER G. H. NORMAN.

The progress of experimental aeronautics has suffered a serious loss by the death of Squadron Leader G. H. Norman, the head of the Engine Research Department of the Royal Aircraft Establishment, who died on 18th August, at the Cambridge Hospital, Aldershot. Squadron Leader Norman had been intended for the Royal Navy and educated at the Royal Naval Academy, Gosport, but afterwards studied at the Royal School of Mines and obtained an associateship. He was also an associate member of the Institution of Civil Engineers and the Institution of Mechanical Engineers and a B.Sc. (Eng.), London. In the early days of the war he served in the Artillery, but was transferred to the R.F.C., where he soon qualified as pilot, and spent thirteen months on the Western Front as Flying Officer and Flight Commander. It was whilst fighting in France that he conceived, made and used what became the standard aerial gun-sight for both the British and American forces.

This sight, which bears his name, was adopted without serious rival during the rest of war, its principal merit being provision of the absolute necessary allowances for the speed of contending aircraft, with the minimum of complications, being thus in marked contrast to other types of sight under trial at the time, most of these being far too complicated for general use in air fighting. After being wounded in action and twice mentioned in despatches, Squadron Leader G. H. Norman was posted to the Armament Station at Orfordness by the late Major Hopkinson, who, impressed by his great constructive ability and enthusiasm for work, placed him in charge of flying at the Experimental Station. From that time to the day of his last short illness his vigorous prosecution of every kind of experimental work was unceasing.

Though officially concerned only with flying at Orfordness, his advice was asked and generally taken in questions connected with almost every branch of the work of the station, and the influence of his clear thinking and great designing ability remains in many schemes and productions with which his name has been in no way connected, for his interest always lay in the work itself. He was by no means a typical inventor in the sense in which the word is popularly understood, that is to say, a man who works by brain waves without labour; his produc-

tions were always the result of careful thought and still more careful experiment. In 1918, when Major Hopkinson took over the Royal Aircraft Establishment, he placed Squadron Leader G. H. Norman in control of the Engine Research Department. As at Orfordness his interests were many and varied and were not confined entirely to engines, but it is probable he will be best remembered by his efforts to reduce the risk of fire in the air or on crash, which he maintained could be almost certainly avoided, given sufficient care in the arrangement of the aeroplane.

Perhaps Squadron Leader Norman's most striking characteristic, and one which effectively endeared him to all who worked with him and under him, was a complete disregard of personal danger, coupled with extreme care for the safety of all under his command. Some very urgent reason was required if he were not to be the first to carry out in person any dangerous experiment which he desired to make. He left behind him a supreme example of this in a flying experiment which he made a few weeks before his death.

An aeroplane had been fitted with an arrangement for spraying fire extinguishing liquid into the engine to extinguish fire in the air. So strongly did he feel the need of personal demonstration that he twice produced fire artificially round his engine in full flight and twice extinguished it.

Perhaps it is to those who fly that an act such as this will make the most intense appeal, but its significance will not end there, it will be remembered as long as the awful possibility of fire in the air remains.

Squadron Leader Norman was a valued member of the Society's Safety and Economy Committee, 1920, and was nominated to serve on the Candidates' Committee this year.

SCOTTISH BRANCH.

SECOND ANNUAL REPORT.

The Executive Committee have pleasure in submitting the second annual report of the activities of the Scottish Branch of the Society.

It is with the deepest regret that they have to record the death of two of their most active and valued members, Colonel Smith Park, D.L., M.V.O., and Mr. Jas. S. Nicholson, D.Sc. Colonel Smith Park was convener of the Finance Committee and a member of the Propaganda and Education Committee, and in spite of his many and varied activities he always found time to help and further the interests of the Society by his prudent and far-seeing counsel.

Mr. Jas. Nicholson, of Glasgow University, was an Associate Fellow and one of the few original members of the Society taken over by the Scottish Branch when it was formed. He was a great aeronautical scientist and a member of our Technical Committee. The Society in particular and aeronautics in general have sustained a great loss by his early death.

It is with great pleasure that we have to record that our Chairman has been raised to the Peerage. The news of this well-deserved honour was received with much gratification by the Executive, which has been duly expressed in their minutes.

Our Society continues to fill a place of considerable usefulness in regard to the cause of aeronautics in Scotland.

1. The Propaganda and Education Committee report that following on last year's success, a course of lectures was again arranged for the engineering students in the Scottish Universities of Glasgow, Edinburgh and Dundee, of which the following are particulars:—

Nov. 1st.—Sq. Leader J. S. Buchanan, R.A.F., from the Directorate of Research Dept. of the Air Ministry, on "Aircraft: General Design."
Nov. 3rd.—Sq. Leader Buchanan on "Aircraft: Details of Construction."
Nov. 15th.—Sq. Leader Hill, R.A.F., from the Royal Aircraft Establishment, Farnborough, on "The Technique of Flight."
Nov. 16th.—Sq. Leader Hill, second lecture, on "The Technique of Flight."
Nov. 22nd.—Mr. J. L. Bartlett, R.N., Chief Overseer, Inchinnan, on "Airships: General Principles."
Nov. 23rd.—Mr. J. L. Bartlett, on "Rigid Airships: Design and Materials."

The attendance at these was good, and it is of note that a course of aviation for the B.Sc. Degree has been instituted at the Glasgow University. The Society is indebted to Professor Cormack for his valuable help in this connection.

With the help of Professor Mellanby, to whom we tender our thanks, a large number of technical college students were interested in the course of aeronautics, and the Hon. Secretary addressed a large meeting of these in October last.

Feeling that they could not otherwise do full justice to the ever-increasing interest shown by the students (many of whom are ex-airmen), the Propaganda and Education Committee decided to form an Ex-Airmen's and Students' Section, and sufficient success has been achieved to show that there is every prospect in the future of useful work being done by the section when the time is ripe.

Good work has been done amongst the cadets of the Glasgow Public Schools and the usual annual Juvenile Lecture was given in March, 1921, by General Maitland on "Airships and their Future." Excellent lantern slides were shown

and great interest was evinced. There was a good attendance at this meeting, which again filled the large hall of the Engineers' Institute.

2. The general lectures held in the Institute of Engineers and Shipbuilders were as follows:—

Oct. 18th.—Major-General Sir Sefton Brancker, on "Aerial Transport." The Right Hon. Lord Weir of Eastwood presiding.

Nov. 8th.—Captain Jones, on "Aerial Photography." Mr. Buyers Black presiding.

Nov. 18th.—Air Commodore Brooke-Popham, C.B., C.M.G., D.S.O., A.F.C., Director of Research of Air Ministry, on "Lines of Future Progress in Aeronautical Research." Lord Invernairn of Strathnairn presiding.

Dec. 2nd.—Mr. C. V. Wallace, Inchinnan, on "Airships and their Future." Colonel Smith Park presiding.

Dec. 15th.—Lieut.-Colonel Strain, Edinburgh, on "Aeroplane *v.* Submarine." Sir John Reid presiding.

Jan. 26th, 1921.—Brig.-General Guy Livingston, C.M.G., on "The Future of Aviation." Mr. George F. Luke presiding.

Feb. 17th.—Major-General Sir Fred. Sykes, G.B.E., K.C.B., C.M.G., on "Developments of Civil Aviation." Lord Invernairn presiding.

Feb. 21st.—In the University, Sq. Leader Arnold J. Miley, O.B.E., on "Sea-planes and Flying Boats." Professor Cormack presiding.

Mar. 10th.—In the Large Hall of the Technical College, Major W. T. Blake on "Flying for Business and Pleasure." Professor Cormack presiding.

Mar. 14th.—In Engineers' Institute, to Cadets of Glasgow Public Schools, Air Commodore Maitland, C.M.G., D.S.O., A.F.C., on "Airships and their Future."

It is interesting to note that the lecture by Lieut.-Colonel Strain, D.S.C., O.B.E., R.A.F., "Aeroplane *v.* Submarine," was printed in the London "Times," and has now been reproduced in the JOURNAL.

A specially noteworthy lecture was that on "The Future of Aviation," by Sir Frederick Sykes, who was entertained at dinner, prior to the lecture, by the Hon. Secretary, when a number of distinguished citizens were invited to meet him.

The lectures were in all cases well attended, and in more than one instance the Large Hall of the Institute was filled. This encourages the Propaganda and Education Committee to continue their policy of getting the very best lecturers possible so as to keep members fully up-to-date in the latest developments of aeronautical science and research.

3. The activities during the year in regard to a most important matter, viz., the future of the Renfrew and Inchinnan Aerodromes, have been considerable, and several interviews took place with the Ministry of Munitions Disposals Board in regard to these. Ultimately the Air Ministry announced that the Renfrew Reception Park alone would be retained, and this on a five years' lease. At Inchinnan only the ground on which Messrs. Beardmore's works stand would be retained, and disposed of along with the Airship Construction Buildings. The Ministry has requested the co-operation of the Society with regard to the future of the Renfrew Reception Park, so that the various local authorities should, by this Society, be co-ordinated, and thus be in a position to co-operate with the Ministry in securing this park as a permanent home of aviation in the West of Scotland. It is intended that the movement in regard to securing the necessary co-ordination of all local parties interested, will be proceeded with in the near future.

4. The Executive have also been interested in the proposal regarding the formation of a Territorial Air Force. It is understood, in connection with the

institution of this force, that Glasgow will be one of the centres in which it is intended to move actively in the near future. Meantime, the Society has compiled a register of the ex-airmen of the district with a note of their flying record, and this will be of great assistance in the event of the Territorial Air Force being formed.

5. During the year negotiations were conducted with the Scottish Aeronautical Society so as to avoid any possible clashing of interests. The line of demarcation was arranged to be the same as that existing between our Society in London and the Royal Aero Club, viz., we to look after the scientific and technical interests of aeronautics, while the S.A.C. look after the social and sporting interests.

6. Activities in the Edinburgh and Dundee branches have been curtailed owing to difficult local conditions, and in Edinburgh, owing to our local Secretary having been called to London. Nevertheless, thanks to the great help of Professor Hudson Beare in Edinburgh and of Professor Fulton in Dundee, the interests of aeronautics have been kept alive, and it is intended, during the coming year, to increase activities in these branches by rendering every assistance possible from Glasgow, both in the way of lecturers and also by visits of members of our Executive to organise meetings, etc.

7. The Finance Committee report that the position in regard to finance is satisfactory, as will be seen from the statement attached. The annual subscriptions were raised by head office to the extent of about 50 per cent. during the year, mainly owing to the increased cost of printing, paper, etc. This has prejudicially affected the membership. But although the membership has been reduced the annual subscriptions still amount to the satisfactory sum of £231. The cash in hand at 31st May amounted to £30, after 50 per cent. of the receipts from subscriptions had been forwarded to the head office. The amount in hand of the Initial Establishment Fund was £500.

It is hoped that in the coming year every member will make a special effort to secure one other member so that the interest in aeronautics may be extended as widely as possible in Scotland and the financial position of the Society consolidated.

INVERNAIRN, *Chairman.*

J. BUYERS BLACK, *Hon. Secretary.*

ROYAL AERONAUTICAL

ABSTRACT OF ACCOUNTS FOR

RECEIPTS.

				£	s.	d.
Cash on Hand at 1st June, 1920				775	16	4
Ordinary—						
Entrance Fees and Annual Subscriptions received from 1st June, 1920, to 31st May, 1921 ...				231	1	0
Extraordinary—						
Special Donations	£5	5	0			
Special Subscriptions for Initial Establishment Fund	75	0	0			
Grant from Glasgow University towards cost of Scientific Course of Lectures on Aeronautics in Glasgow University	25	0	0			
Grant from Edinburgh University	25	0	0			
Grant from Dundee University	25	0	0			
One half of Dundee Subscriptions received	3	13	6			
Interest on Deposit Receipts	14	16	9			
Interest on Glasgow Corporation Loans	10	19	0			
Interest on Glasgow Corporation Deposit Receipt...	3	18	1			
				188	12	4
				£1195	9	8

Glasgow, *21st June*, 1921.—Audited and found correct.

SOCIETY (SCOTTISH BRANCH).

THE YEAR ENDED 31st MAY, 1921.

EXPENDITURE.

	£	s.	d.	£	s.	d.
ORDINARY—						
Amount paid Head Office, London, being one half of Annual Subscriptions received by this Branch from 31st March, 1920, to 31st May, 1921, as per arrangement	141	0	6			
Miscellaneous Expenses of Lectures	125	13	1			
Printing	19	12	6			
Typewriting Supplies, Stationery, etc.	23	17	5			
Postages, Telegrams and Trunk Calls	23	12	6			
Clerical Assistance for year	102	0	0			
Advertising	22	7	6			
				458	3	6
EXTRAORDINARY—						
Hon. Secretary's Travelling Expenses, *re* Meeting Air Ministry and Minister of Munitions ...	9	16	6			
Paid for use of Office and Staff, Typewriters and Sundry Expenses from 31st August, 1919, to 31st May, 1921	196	19	2			
Bank Interest	1	0	0			
				207	15	8
BALANCE: Surplus of Receipts over Expenditure made up as follows:—						
Cash in Bank	43	3	4			
Cash with Corporation of Glasgow, on loan ...	500	0	0			
	543	3	4			
Less: Cash due Secretary	13	12	10			
				529	10	6
				£1195	9	8

(Sgd.) J. WYLLIE GUILD & BALLANTINE, Chartered Accountants, *Auditors*.

THE WILBUR WRIGHT LECTURE.

SCIENTIFIC METHODS IN AERONAUTICS.

BY G. I. TAYLOR, F.R.S.

Introduction.

When your Secretary, shortly before Easter, wrote to ask me to give the Wilbur Wright Lecture he made me give him a title before writing the lecture. I therefore had to think of one which would fit any lecture I might conceivably want to give, so that when I came back after Easter I should be able to pick out one of those subjects connected with aeronautics with which I have been specially concerned, and discuss the results arrived at. When, however, I came to sit down to write the lecture itself it struck me that it might be more interesting to a general audience if I followed the line which is perhaps most obviously indicated by my title, and directed my remarks towards tracing and comparing some of the principal lines of argument which have been used in aeronautical research, without going particularly deeply into the results.

When one comes to review the whole range of experiments and theories in aeronautics one is apt, if one is cursed with a passion for arranging things, to set up a series of files headed Propellers, Aerofoils, Engines, etc. This classification, which is no doubt the most useful one for the engineer, is unsuitable for the purpose I have in mind this evening. For this purpose I shall imagine aeronautical knowledge to be arranged roughly in a single series according to the number of links which intervene between the experiment or theory concerned and its application to aeronautical practice.

At the beginning of the series come direct tests in the air on the final product, tests of the speed and stability of an aeroplane, the flight of a bomb or the durability of a balloon. Next come tests of engines on test beds. Then the series will pass through various kinds of knowledge derived from experiments with models. Next will come stability calculations in which the results of model experiments are used, and finally the series will end among the fundamental principles of aerodynamics and hydrodynamics.

I propose this evening to pass along this series picking out some of the methods of solving aeronautical problems which have fallen within my experience, by way of illustration of the principles involved. These examples will, I hope, serve to throw into prominence the comparison which I want you to make between the methods of applied and those of pure science.

The worker in applied science can apply more or less direct methods which lead him continually nearer to his goal. The pure scientist has such formidable difficulties to encounter that direct methods are usually impossible. He must apply quite indirect methods, which constantly carry him into other fields of research.

The differences in the methods of applied and pure scientific research naturally give rise to differences in the conditions most suitable for carrying them out. These again may give rise to differences in the kinds of organisation which are likely to be of most assistance in furthering the two kinds of research. It is in the hope that I may be able to convey to people who are not themselves engaged in research some idea of its methods, some idea of its difficulties and some idea of the conditions which are most favourable for carrying it out, that I have embarked on my subject this evening.

Full-Scale Experiments.

Returning now to the series into which we may imagine aeronautical knowledge to be arranged, we begin with direct tests in the air.

The only general scientific principle which appears to be involved in passing

from these tests to the performance of aeroplanes lies in the assumption that the same results always follow from a given sequence of causes. All of us, I suppose, are willing to admit this principle in our calmer moments, though I must confess to moments of exasperation when experiments went wrong and I was almost ready to deny it.

As an example of full-scale research one might be expected to select some method of dealing with the problems which occur in full-scale research on aeroplanes. On the other hand this Society has had so many accounts of these methods that it seems preferable to select an example in which experiments were made on the aerodynamic behaviour of some other body than an aeroplane. The body I have in mind is the flechette or aeroplane dart, which appeared and disappeared in the early stages of the war.

Some time in August, 1914, the War Office sent down to the Royal Aircraft Factory at Farnborough, where I was then stationed, a steel dart of French manufacture which was intended to be dropped from aeroplanes on to troops. They asked whether the R.A.F. could suggest any improvements. Mr. Busk, who was then in charge of the experimental side of the R.A.F., turned the job over to Professor Jones, who, after many experiments, finally decided that a dart consisting of a short, pointed steel rod forced into a piece of thin brass radiator tube might give better results and be cheaper to manufacture than the French all-steel dart. The two darts are shown in Fig. 1.

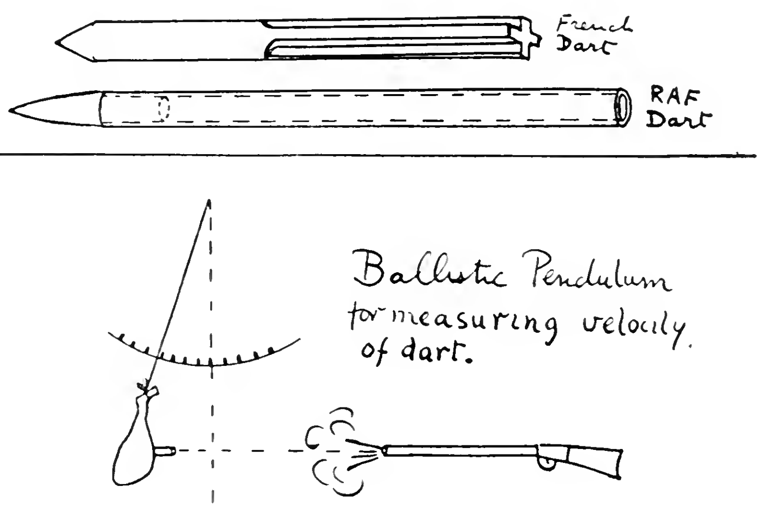


FIG. 1.—*Experiments on aeroplane darts.*

Having designed the dart, the next thing was to test its performance in the air, and it was at this stage that I became connected with the experiments. The first point to decide was the proper length to make the radiator tube. With this end in view we repaired to Pyestock chimney, a disused factory chimney 130 feet high, near Farnborough, and dropped darts with various lengths of tail tube down the middle. At first we had supposed that if a dart were made so that it would point into the wind when suspended horizontally at its centre of gravity, it would fall straight. This, however, turned out to be untrue. Unless the tail tube were considerably longer than the length necessary for stability when suspended at the centre of gravity, the dart would whirl round about a vertical axis, lying out to some 50 or 60 degrees from the vertical. When, however, the tail tube was made some 4½ or 5 inches long the darts were found to fall quite straight down the chimney.

The next thing to find out was whether these darts would do any damage when they fell from an aeroplane on to troops. Direct experiments were impossible, partly owing to lack of volunteers to act the part of troops, and partly owing to the difficulty of hitting a target from an aeroplane in flight. It was therefore necessary to have recourse to indirect methods, though you will notice that the object experimented on was still the dart which it was intended to use in actual warfare.

The most obvious indirect method appeared to be to determine first the velocity with which the dart would arrive at the ground when dropped from an aeroplane, and then to project it with that velocity at the material, the penetration into which was to be tested.

To determine the velocity with which the dart would reach the ground it was merely necessary to determine its resistance. Quite a rough determination was sufficient, and this was obtained by dropping the dart, point downwards, through a stream of water which was rising in a tube. The speed of the upward current of water was adjusted till the dart would only just fall through it. The resistance was then equal to the weight of the dart.

From this experiment it was possible to make a rough estimate of the speed with which the dart would reach the ground. The next step was to find a method of projecting it at that speed. This was done by means of a Service rifle, bored smooth so that the dart would just fit it, and fired with a reduced charge. In order to find out how much charge was necessary, the dart was fired into a ballistic pendulum, which consists, as you probably know, of a heavy body hanging on a string. It was possible to calculate the velocity of the dart from the distance to which the pendulum swung out from its position of equilibrium. Conversely it was possible to calculate how far the pendulum should swing when struck by the dart at the velocity with which we had found that it would reach the ground. This calculation was made and the charge in the cartridge behind the dart was reduced till the pendulum was observed to swing through this distance.

As one of the questions we were asked was what would be the penetration of these darts into flesh and bone, we made our ballistic pendulum out of a leg of mutton, and so did our penetration experiments at the same time as the experiments to find the amount of charge necessary to propel the dart at the required speed. The sketch in Fig. 1 gives an idea of the experiment.

Having satisfied ourselves that the darts would do the necessary amount of damage if they struck their target, it remained to find out what chance they had of hitting that target.

For this purpose direct experiments were possible. Mr. Busk took a box containing a few hundred darts and dropped them from an aeroplane flying at about 500 feet above the aerodrome. Professor Jones and I then went carefully over the ground threading a little square of paper over each dart as we found it sticking in the ground, to mark its position. In this way we were able to make an estimate of the chances of hitting troops in any given formation. They turned out to be extremely small.

In connection with these experiments I remember a curious incident. While Professor Jones and I were standing looking at the scene which consisted of hundreds of little pieces of paper each transfixed by a dart, a highly polished cavalry officer came up on his horse and asked us what we were doing. We told him we were marking for an aeroplane which was dropping darts. His only comment was "Well, if I hadn't seen it, I should never have believed you could make such accurate shooting from an aeroplane." I leave you to trace his simple thought.

Aeroplane darts were practically never used by British pilots in warfare. There is of course a very adequate reason for this. The danger line of a

dart is a vertical line. For troops spread over the ground, therefore, each dart gives rise to a single danger spot. If, however, the same weight of material were used to make bombs, some of the danger lines of the pieces would be horizontal lines and the chance of hitting troops would be enormously greater. It is interesting to notice however that this was not the reason given at the time. We were told that British pilots refused to use darts because they regarded them as inhuman weapons. Pilots—and I speak as a pilot myself—are a most conservative race. Gunpowder as a means of propelling projectiles had acquired respectability through centuries of use, but gravity was a new and inhuman force. Bombs at that time were regarded as hardly respectable. Presumably the explosion at the end of their flight made up to a certain extent for the loss in caste which they had suffered in using the inhuman force of gravity during their descent. Darts which depended only on gravity were entirely disreputable.

In describing these experiments on darts I have tried to bring out the kind of problem which comes up in full-scale experiments when it is not possible to reproduce, during the tests, the exact conditions under which the article tested is to be used. The difficulties are frequently not very great and are of a type which a competent engineer can tackle.

Model Experiments.

I now pass on to cases in which it is not possible, or else merely undesirable, to perform full-scale experiments. In these cases we have to rely on experiments with models and on calculations which themselves are chiefly based on model experiments. The essential scientific question which arises whenever such experiments are carried out is that of how far they really represent, on a different scale, the action of the mechanism which is the subject of investigation. This question has to be discussed separately in each case, but there are a few general rules to which I may refer, and I will afterwards give an example to illustrate their application.

This is hardly the time or place to enter on a discussion of the principle of dynamical similarity on which the relationship between model and full-scale experiments rests. The principle itself is well understood; it is the application of it which leaves room for discussion and mistakes.

Suppose now that we know all about the motion of some dynamical system; and suppose we alter all the lengths in a certain ratio, all the velocities in another ratio and the masses in another ratio. We shall then find that we have altered all the other measurable quantities connected with the system in certain fixed ratios. If, for instance, we have doubled the lengths and kept the masses of corresponding parts unaltered, we will have decreased the densities of corresponding parts in the ratio 8 : 1, because we will have multiplied their volumes by 8 without altering their masses.

The principle of dynamical similarity amounts to a statement that the new system will be dynamically possible if all the forces are altered in a ratio which is equal to the product of the ratio in which the masses are altered multiplied by the ratio in which the accelerations are altered. It is, in fact, merely a direct application of Newton's law of motion, combined with the purely geometrical, or at any rate non-dynamical, principle that from any system one can derive a similar system by altering three, and only three, independent dimensions in any arbitrary ratios.

The difficulty in applying the principle is due to the fact that the forces concerned are due largely to causes which are not completely under our control. When we alter the dimensions of the system we alter the forces which arise in it owing to the weight, elasticity or other physical properties of the material

of which it is constructed. Unless these forces are altered in the correct ratio the new system will not be dynamically possible.

Unfortunately if, as is almost invariably the case, there are more than three distinct causes of forces in the system, it is impossible to find any system in which the forces due to all the causes are in the correct ratio.

It is therefore impossible ever to get complete dynamical similarity. On the other hand, it is frequently possible to guess, or it is known by experiment, that some of the causes produce very little effect on the motion. The art of using model experiments to deduce results, applicable when the dimensions of the system are altered, lies chiefly in selecting which of the possible causes of the forces in the system may safely be left out of consideration.

I do not propose to take up your time with a discussion of the ordinary application of the theory of dynamical similarity to experiments on the wind forces on models of parts of aeroplanes when placed in a wind channel. This has been discussed at great length both here and elsewhere. For the benefit of those who have not studied dynamical similarity, however, I may give a simple example of its application.

Model and Full-Scale Yachts.

Consider the relationship between the performance of a small sailing yacht and a model of it on a scale of one inch to one foot. The question is, could the performance of the model be used to find out anything about the performance of the full scale yacht? If so under what conditions?

In making our model experiment there are two necessary relations between the dimensions. The first is due to the fact that we are using the same liquid, water, in the two cases. For this reason the density of the model must be the same as the density of the full-scale yacht. The other condition is that the value of gravity, which is evidently a controlling factor, must be the same in both cases since both the model and the full-scale yacht sail on the earth's surface.

Now gravity has the dimensions of acceleration or rate of increase in speed. In order that accelerations may be the same in the two cases, when the linear dimensions of the system are altered, the speeds must be altered in proportion to the square root of the alteration in length. In the present case since the lengths are reduced from the full-scale to the model yacht in the ratio 12 : 1, the speeds must be reduced in the ratio $\sqrt{12} : 1$, or about $3\frac{1}{2}$ to 1.

If, owing to some other factor not yet considered, such as the viscosity or stickiness of the water, the model system is not similar to the full-scale system when the speeds of similar parts are in the ratio of the square roots of the lengths, then it will be impossible to use a model to represent the full-scale system. On the other hand it has been shown by experiments on the resistances of models of different sizes that when the speeds are in the correct ratio the systems are very nearly similar. Hence the use of a model is justified.

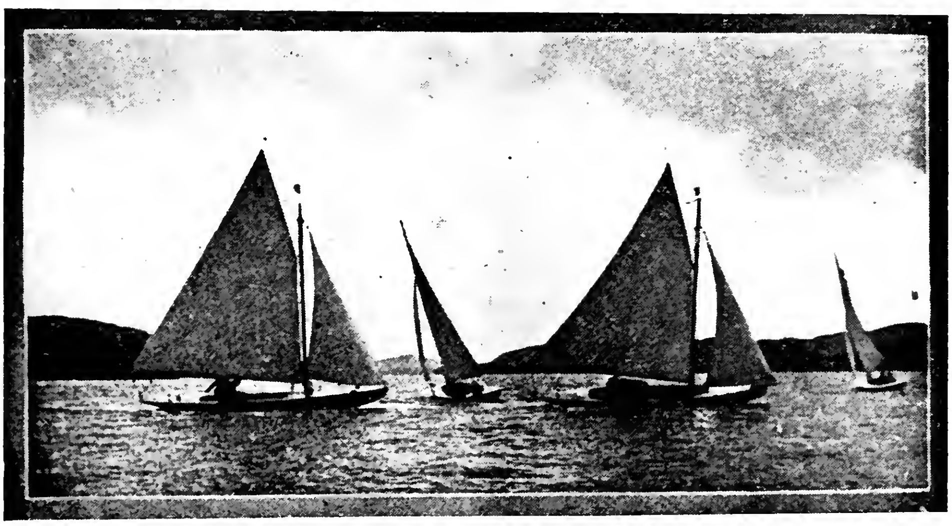
Now let us see how this works out in practice. Our full-scale yacht will be designed to sail her best with a moderate sea breeze of 25 miles per hour, and she then heels over through an angle of 10 to 15 degrees. Our model yacht 1/12th scale should therefore sail her best in a breeze of $1/\sqrt{12}$ times 25, or about seven miles per hour. Wind measurements made about a foot above the surface of an inland pond show that this is just about the speed of a "moderate breeze" there.

Models of about 1/12th scale are therefore good representations of full-scale yachts when they are sailed on an inland pond, because the wind-speed, close to the surface of the pond, happens to be on the average only $1/\sqrt{12}$ of the wind speed at sea. On the other hand you may have noticed that a model

yacht sailed at sea on a day when small boats are sailing well, will lie over almost flat on the water.

You will notice that when similarity is obtained the speed of the model should be $1/\sqrt{12}$, *i.e.*, about 2/7ths of the speed of the full-scale yacht. A yacht about 24 feet long will, when sailing her best, do seven miles per hour. A model yacht 24 inches long should therefore be capable of doing two miles per hour. Everyone who has watched boats on the Round Pond will recognise the truth of this statement. If one starts a good 24in. model boat across the Round Pond, one has just time to walk round to the opposite side before she gets there. A man walks about three miles per hour and his walk is about $1\frac{1}{2}$ times as long as the model's course. The model must therefore go at about two miles per hour. If therefore we take a successful model yacht about 24ins. long we may reasonably expect an exact replica 24ft. long to sail well in average weather at sea.

On the other hand, if we take a successful yacht 24ft. long, which sails well in a wind of 25 miles per hour, and make an exact replica four times the



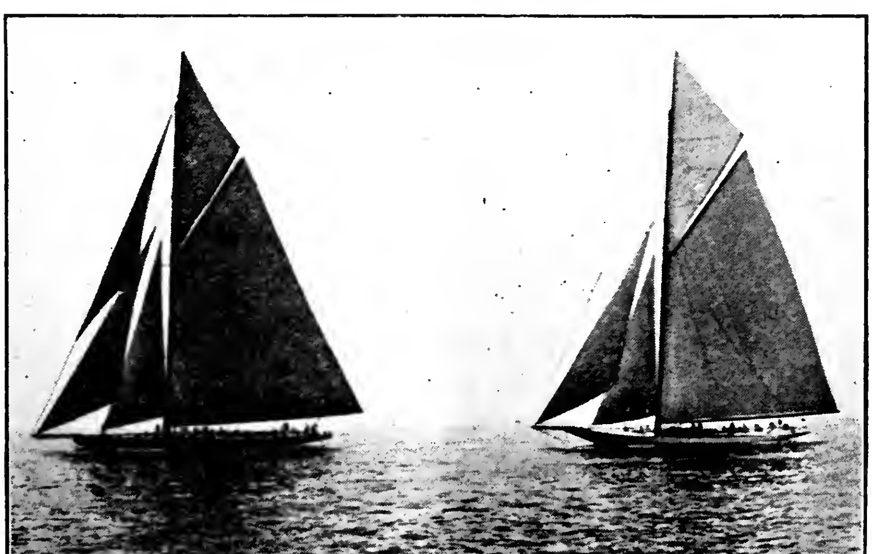


FIG. 2.—*Photographs showing comparative sizes of sails in large and small yachts. Above, 24-footers. Below, "Shamrock" and "Resolute" in race for the America's Cup. The photographs are reduced so that the lengths of the hulls appear the same in the two cases.*

size, that is 96ft. long, she will only sail her best in a gale of $\sqrt{4 \times 25}$, *i.e.*, 50 miles per hour. For this reason, therefore, large yachts need to have larger sails in proportion to their length than small ones.

I have here a slide (Fig. 2) showing (bottom photo) "Shamrock" and "Resolute" in the American Cup races last year, and (top photo) a race between yachts about 24ft. long. The scale of the smaller boats is increased till the two sizes appear the same length on the screen. You will see that the large yachts have much larger and higher sails in proportion. Even with these enormous sails the big yachts do not heel over to anything like the same extent as the small ones. I have here a slide (Fig. 3) showing "Shamrock" sailing on the day when her racing was abandoned owing to the high wind. You will see that she is hardly heeling over at all.

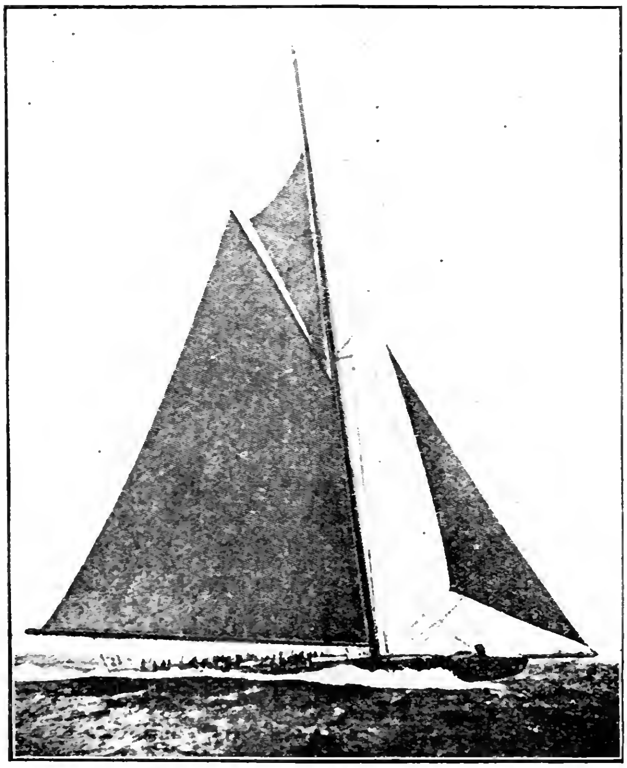


FIG. 3.—"*Shamrock*" *sailing on the day the race was abandoned.*

I have chosen the example afforded by model yachts because it seemed to me that observant people must recognise that the results arrived at by the argument of dynamical similarity are true in this case, and that when one recognises that the results are true it is much easier to understand the argument by which they are obtained.

Example of Bomb and Pilot Bomb.

We may now pass on to consider the way in which models may be used to solve more complicated problems in aeronautics. For this purpose I have selected an example from my own experience which has very little interest apart from the method of solution, and, as things turned out, no military value. Some time during 1915 various inventors got hold of the idea that the effectiveness of bombs was reduced by reason of the fact that they do not explode till they touch the ground. They thought that if a small pilot bomb could be made to travel in front of the explosive bomb, and if the two were connected by a wire which caused the upper bomb to explode as soon as the pilot bomb hit the ground, more damage would be done.

Accordingly they set themselves to designing elaborate electrical arrangements for exploding the upper bomb and complicated methods by which the pilot bomb could be projected from inside the main bomb during the descent. None of them seemed to notice the real difficulty of the problem, which is that of making the pilot bomb travel ahead of the main bomb when there is a connecting wire between them. At any rate those who mentioned it at all dismissed it with the inventor's general utility phrase, " Any competent engineer can do the rest."

One bomb made by an inventor was, I fancy, actually tried, and it was found that the pilot bomb came down well behind the main bomb.

When I was asked to examine the conditions under which a pilot bomb could be made to carry a wire ahead of the main bomb, the first idea which came up was naturally that if the upper bomb could be slowed up by some artificial means the scheme would certainly work. On the other hand the slower the bomb, the less accuracy would be expected in hitting the mark. It seemed likely, therefore, that a compromise would be necessary in which the bomb would be slowed up as little as possible consistent with the proper action of the pilot bomb.

Starting then with the idea that bombs should fall at least at 500ft. per second to ensure accuracy in aiming, I set myself to find out how much wire the best possible shape of pilot bomb could carry out in front of the main bomb at this speed. The first thing we found was that at 500ft. a second it was impossible to see how the pair fell. Accordingly I set myself to design a dynamically similar experiment in which everything happened more slowly. I found that if the main bomb were slowed down by attaching a small parachute to it so that it fell at 100 or 150ft. a second, it was quite possible to watch the action of the pilot bomb, especially if one stood just where it was expected to fall—it was not loaded of course.

Now let us see how the principle of dynamical similarity applies. Since gravity is evidently one of the most important factors, it will be seen at once from my previous remarks that to obtain a dynamically similar system in which the model bomb falls at 100ft. per second, that is 1/5th the speed of the full-scale bomb, it is necessary that the linear dimensions shall be reduced in the ratio 1 : 25. This would reduce the model to a very diminutive size, its weight being only 1/5,000th of the weight of the original system. Under these circumstances it would be impossible to see it, even when it was moving at only 100ft. per second.

It appears therefore that we cannot usefully perform an experiment in which similarity is completely preserved so that the accelerations and the densities are the same in the two cases.

On the other hand since the cause of the peculiar behaviour of the system appeared to be the force of the air acting sideways on the wire and driving the pilot bomb off its track, it seemed likely that the essential feature in the situation might be the ratio between the pull exerted by the pilot bomb and the resistance which the wire would experience if it were moved transversely, at the speed of descent. If this relationship were true then curves assumed by the string in all possible cases for which this ratio was given, would be similar.

This was found to be true. Here is a slide (Fig. 4) showing the results of experiments in which the bomb was dropped at 100ft. a second, with various lengths of connecting string.

As the length of string was increased the pilot bomb took up a position which was progressively farther and farther from the vertical line through the main bomb. A certain length of string brought the pilot to its lowest depth below the main bomb. The string then appeared to leave the main bomb horizontally.

As the string was lengthened still farther the pilot got dragged back by the wire till finally it was in a position behind the main bomb.*

In order to see whether the similarity relationship which I had guessed at was true, I took a certain easily recognisable shape for the connecting string, namely the one at which the pilot bomb was at its maximum depth below the main bomb. I then doubled its length and halved its diameter so that its resistance should remain approximately unchanged. I found that the string took up the same shape as before.

Next I tried increasing the speed to 150ft. per second and decreasing the thickness of the string in the ratio $(1.5)^2 : 1$, at the same time keeping the pull of the pilot bomb constant. Again the string took up the same shape.

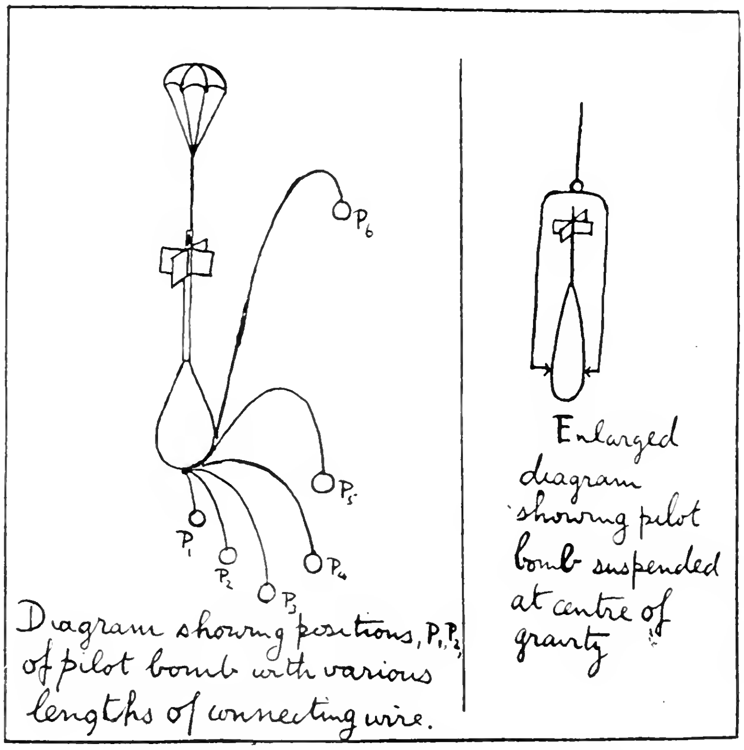


FIG. 4.—*Bomb and pilot bomb.*

It appears therefore that the predicted similarity relation is true.

The problem is therefore solved and one set of results with the model system gives a designer all he wants in designing any possible system consisting of a bomb and pilot bomb.

In describing these experiments I have tried to bring out the fact that the use of models does not end when it is impossible to get complete dynamical similarity, though the validity of the results arrived at in other cases must be verified experimentally by comparison of models on different scales. Nearly the whole of the model work now carried out is done under conditions in which there is no theoretical reason for supposing that dynamical similarity exists. On the other hand there is plenty of experimental evidence that model experiments, of the type done at the N.P.L. for instance, do very nearly agree among themselves even when the scales are very different; and that they do, in fact, very nearly represent the state of affairs in the full-scale.

Aerodynamical Stability.

Model experiments afford us a method of obtaining information which is

* When the pilot bomb got behind the main bomb it ceased to travel steadily, continually lagging behind and overtaking the main bomb.

useful in problems connected with aeronautical engineering. They do not as a rule help us directly in understanding the principles of aeronautics, for it is just as difficult to understand the model as it is to understand the full-scale mechanism.

The most important step which has yet been taken in understanding the principles of flight is that of Professor Bryan. Bryan treated the aeroplane as a rigid body acted on by forces which he specified in a form suitable for the application of dynamical equations. He was not concerned with the manner in which the forces arise owing to air pressure. He then investigated the oscillations and motion of an aeroplane in general terms.

Afterwards he made certain assumptions about the forces due to air pressure which were incorrect, and led to incorrect predictions about the behaviour of aeroplanes. The fact that his predictions were not all correct does not however detract, in the least, from the value of his work; for when the forces on parts of aeroplanes came to be measured by means of models, and when these results were substituted in Bryan's general equations in place of his original assumptions, it was found that the new results agreed very well with the observations of the behaviour of a full-scale aeroplane.

I need hardly take up your time with a discussion of the work of Bryan, Lanchester, Bairstow and Busk on aeroplane stability. I need only say that, as a result of their efforts, we have a pretty complete general understanding of the dynamics of flight, though, of course, we are no nearer understanding the more fundamental problem of how it is that the forces on a body moving in the air arise. Of this I shall have more to say later; in the meantime, an example of the application of Bryan's equations may be of interest.

Some time in 1915, it was required for some war purpose to carry a flat stream-line weight beneath an aeroplane at the end of a wire. In designing this apparatus we first made a flat weight and then put a fin behind it so that, when pivoted at the centre of gravity, the weight would head into the wind.

When we came to try this apparatus in the conditions under which it was to be used, we found that instead of hanging steadily the weight executed rapidly increasing oscillations, so that it quickly became quite dangerous.

We tried increasing the size of the fin, but that only seemed to add to its fury. At this stage it seemed that theory might be expected to help us by explaining the cause of the oscillations. I therefore modified Bryan's equations so as to make them applicable to a body hanging by a wire, and found that this rapidly increasing oscillation was exactly what the equations would lead one to expect. On the other hand I found that theory indicated that if, instead of increasing the fin behind, one were to cut it down till the weight would only just head into the wind when pivoted at its centre of gravity, then the increasing oscillations ought to disappear and the weight should travel smoothly at the end of its wire.

These conclusions were most strikingly verified. The weight was about 8ins. across. The fin was reduced by paring off successive small amounts from its after edge.

It was found that the weight remained unstable till its fin was only $\frac{1}{8}$in. deeper than the fin which was necessary in order to prevent the weight from lying broadside on to the wind. In this small range, involving only $\frac{1}{8}$in. of depth of fin, the weight travelled perfectly truly. I doubt if we should ever have found this small region of stability if we had not had Bryan's general equations to help us. A rough sketch of the weight and fins is shown in Fig. 5.

Place of Pure Science in Aeronautics.

So far I have dealt only with scientific methods which have a direct or at any rate an obvious indirect bearing on aeronautics, investigations in which the

scientist has in view, at any rate, some question relating to aeronautics. It seems to me however that these are not the kind of investigations which are likely

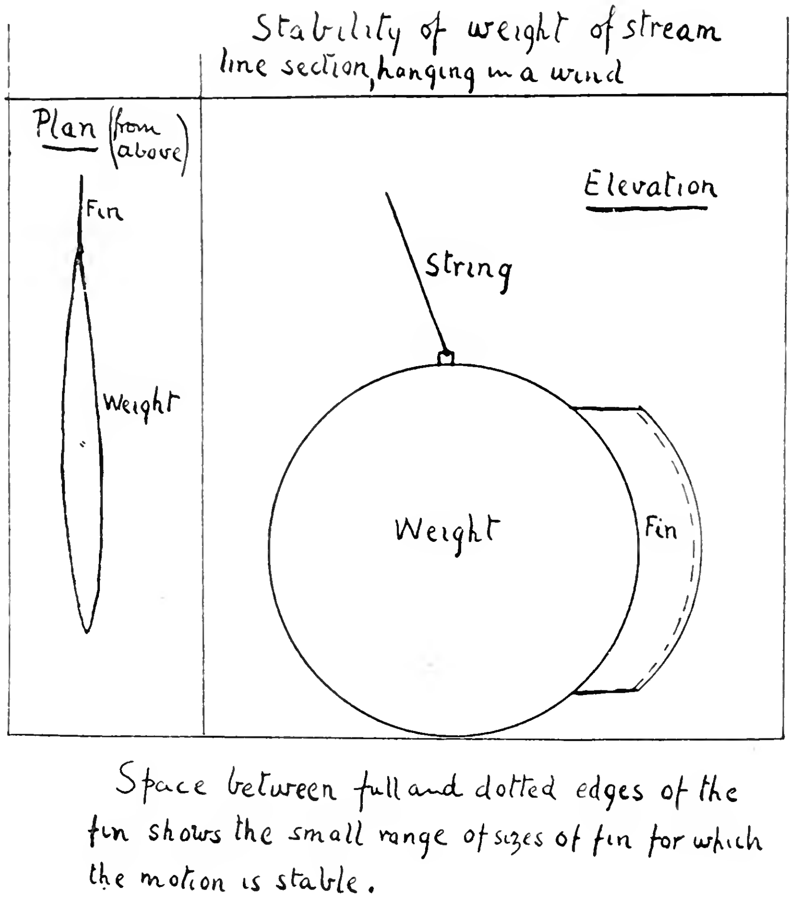


FIG. 5.—*Stability of weight of streamline section hanging in a wind.*

to produce the greatest or the most profound changes in the science. Perhaps I can explain what I mean better by an imaginary case.

Try to imagine a race of men who lived entirely for golf, who thought about it at meals, practised it by day, dreamed about it at night and talked about it always. I do not suggest that such a race ever existed, but to the philosopher no conception is too revolting to be used in the practice of his art. This race would no doubt develop a class of highly specialised technical experts who would invent balls and clubs of the most complicated character, devise special apparatus for exercising the muscles used in doing a drive, invent special head-rests designed to fix one's eye on the ball, etc., etc. By means of this kind they would perhaps increase their drives from 200 to 300 yards.

At the same time there might exist a few lunatics who were so mad that they took not the slightest interest in golf, but preferred to spend their time in foolish inquiries about the action of food or drugs in promoting the selective growth of certain muscles, the factors which govern inheritance of physical characteristics, or other useless investigations. The chance that these lunatics would ever find out anything which had any bearing on golf would be extremely small; but it would always be on the cards that when they had really got a thorough understanding of the mechanism of the body, they might see how to breed a race of golfers who could drive 4, 5, 6 or 700 yards.

At any rate they, and not the technical experts, would be the only people who had any chance of making a really fundamental improvement in the length of a drive.

If our poor ignorant forefathers a hundred years ago had had the inestimable advantage of a Minister of Transport, do you suppose that he would have invented the twopenny tube? Of course not. His time would have been fully occupied in regulating the height at which a horse must carry his port and starboard lights. Perhaps the Wells of that time may have pointed out that the number of collisions is proportional to the square of the number of vehicles on the road, and that, at the rate of increase in population then current, movement on the surface of the earth would be impossible in 150 years or so. He might even have suggested that the transport problem would be solved by tubes underground in which the traffic went in one direction only.

None of these things would have brought electric railways the slightest bit nearer. The discoveries which made electric transport possible were not made by transport experts at all, but by Oersted and Michael Faraday, whose researches into the magnetic and mechanical effects of currents of electricity were instigated by their interest in pure science alone, and had no connection whatever with transport problems. They may even have been people who believed that rapid transport is on the whole a bad thing; that every increase in the facilities for travel merely decreases the size of the world instead of enlarging one's range; that the easier it is to get to China, say, the more European travellers would one find when one got there, and the less worth while would it be to go there. With these reactionary sentiments I should find myself in thorough agreement, but I should hardly expect to find sympathisers in this Society.

I may seem to be wandering from the point, but I introduce this matter to illustrate the idea that the far-reaching discoveries which revolutionise any branch of applied science are liable to be made by people who have no knowledge of or interest in the science in question, but who are chiefly interested in fundamental principles. What particular branch of applied science it is whose foundations they are examining, seems to me of very much less importance than the fact that they are examining foundations, rather than superstructure.

The difference between the methods by which a pure and applied scientist approaches his work is of some interest. If one compares the lives of distinguished applied scientists like Siemens, Marconi or Wilbur Wright with those of pure scientists like Kelvin or Lord Rayleigh one will at once be struck by the colossal difference in the range of investigations attacked by the two types of men.

The investigations of Lord Rayleigh extend over many branches of heat, light, sound, electricity, astronomy, hydrodynamics, aeronautics, molecular physics, mathematics and even psychical research. The investigations of Siemens are practically confined to one branch of electricity, those of Marconi to another and those of Wilbur Wright to one branch of aeronautics. This is not due altogether to lack of breadth of vision on the part of applied scientists. It is partly, no doubt, due to the fact that several applied sciences which are completely different in their aims rest on the same foundations, and a man who is dealing with those foundations, therefore, affects several applied sciences; but it is more I think due to the difference in the nature of the difficulties which are encountered in the two cases.

The applied scientist has in view a definite aim. He may not see the whole course of his work marked out before him, but he does at any rate see the direction in which he must go. The difficulties which he encounters are of a kind which perseverance, courage and ability will enable him to overcome. The labour is often very great, so great indeed that it absorbs all his attention, but on the whole he sees himself slowly and continually approaching his goal.

The pure scientist on the other hand finds difficulties in his path of such a formidable nature that it is often quite useless for him to attempt a straightforward approach to any particular distant goal. If he limits himself to a direct

attack he will in all probability find himself at the end of his life at exactly the same spot where he started as a young enthusiast. He is therefore forced to move in any direction in which it appears possible to proceed. The difficulties of his subject actually force him into other fields of science.

The realm of science may be compared with a mountain region in which the lower slopes are full of impossible precipices while the upper parts consist of long and difficult glaciers and snow slopes. The mountains are all connected together at their foundations, but the peaks are widely separated.

The applied scientist is like a mountaineer who forces his way to one of the summits across glaciers and through snow fields. The pure scientist is like the rock climber who, finding himself confronted with an impossible precipice, traverses out to one side on to another slope. Here perhaps he finds a short and difficult chimney which lands him at a higher level, from which he may, or may not, be able to traverse back to the peak on which he originally set his fancy. At any rate he is at a higher level than he was at the beginning.

In the course of his traverses prospecting for new routes upwards the climber will very likely see attractive possibilities about another peak, possibilities which could not be seen from a lower level. In that case he will, if he is wise, forsake his original scheme and try the new place.

Examples from Author's Experiment.

I have now tried to explain what I consider to be the main difference between research in pure and applied science. You will see from what I have said that it is to be expected that researches which were begun with a view to throwing light on the principles of aeronautics should, at times, have no obvious connection with aeronautics at all. With this by way of apology let us, shall I say, descend from the sublime to the ridiculous, while I mention a few of the bye-paths into which a search for fundamental principles in aerodynamics has led me.

The problem with which one is confronted is to find out how the air moves round a solid body which moves through it; and how the pressures which result from its motion arise. Practically no headway at all has been made towards the solution of this problem in any single case. The difficulty lies in the fact that at the surface of the body the air is churned up into a disturbed eddying state.

In the ordinary theory of hydrodynamics a fluid is contemplated which has no viscosity or stickiness; it slips without friction past the surface of the solid. The mechanics of such a fluid is amenable to mathematical treatment, and the result is arrived at that the air exerts no force on any body which moves uniformly through it.

The ordinary hydrodynamical theory is therefore quite inapplicable to the case of bodies moving steadily through the air. One must seek for the explanation of the forces which are observed in these cases in the action of the eddying region on the flow. The great difficulty is to represent that eddying region mathematically, and to explain how it arises. My first efforts were directed towards finding out everything I could about this eddying motion.

In the first place, though I could find no way of representing, mathematically, the actual motion of each particle of fluid, I succeeded in finding a way of expressing the effect of the whole turbulent region on the average condition of the fluid in certain cases. In the case of the turbulent region which occurs when the wind blows over the surface of the earth, I found relationships between various things which depend on the existence of the turbulent motion. I connected the rate at which the wind varies above the surface of the earth, the daily variations in the temperature at the top of the Eiffel Tower and the thickness of the fogs on the Grand Banks of Newfoundland, which I had previously

measured during the summer of 1913. I calculated also the amount of friction which the wind exerts on the ground, and found that it is the same as that measured in a wind tunnel, using a smooth flat plate placed edgewise in the wind.

These results seeming promising, I next tried to find out something about the way in which energy is dissipated in eddying motions. I found at the outset from mathematical considerations that in order that energy may be dissipated in eddying motion, this motion cannot be confined to two dimensions. It must extend to three. On the other hand if the wind is blowing over a large expanse of flat ground one would expect, *à priori,* that the friction on the ground might produce eddies of wind like rollers which would have the effect of making the variations in wind occur in the direction of the wind and vertically, but not across the direction of the wind.

To investigate this question I had a light wind vane made* which automatically recorded the horizontal and the vertical direction of the wind at any time. This instrument showed that the wind in eddying motion varies in a cross-wind direction through exactly the same amount on the average, that it varies in a vertical direction.

Further evidence showed that the variations of wind along the direction of the wind are exactly the same as in the other two directions. That, in fact, there is in the case of a natural wind an equipartition of eddy energy in all directions in space.

The method adopted for calculating the energy dissipated in eddying motion seemed to be also available for calculating the energy dissipated in tides. My calculations showed that a very much greater amount of energy is dissipated by the tides than had previously been supposed. This result appeared important because it showed that water tides may be the cause of the gradual slowing down of the earth which astronomers have been able to observe. The question has lately been taken up by Dr. Harold Jeffreys, who applied my method to all existing basins where tidal energy might be dissipated, and showed that the tides do in fact dissipate just about enough energy to account for the observed slowing down of the earth.

Already you see how investigations which were begun in relation to aerodynamics have invaded meteorology, tidal theory and astronomy. I need hardly follow their further ramifications into investigations of the oscillations of tides in gulfs and rectangular basins, the height of tide in the Bristol Channel, the dissipation of sound in the atmosphere, the cooling of thermometer bulbs wetted with organic liquids, the production of fog, etc.

Not long ago I returned to the question of the motion of bodies in fluids, and tried to attack it from a new aspect. Instead of trying to find out about the turbulent motion at the surface of the body, I began to search for cases in which the flow does not depend on the turbulent region. I found a rich field in the dynamics of rotating fluids. I cannot here go into the arguments which induced me to believe that I ought to be able to predict certain types of result about the dynamics of rotating fluids; and that, contrary to all experience with non-rotating fluids, these mathematical results were likely to be true experimentally when tried with real fluids. I see no way in which the arguments can be explained in non-mathematical terms. I must ask you to take them on trust therefore, and to look at a few slides showing how completely mathematical theory is verified.

First of all I predicted that if a solid cylinder of the same density as water is towed through a rotating liquid, say from side to side of a round, rotating

* This was kindly undertaken for me by Mr. W. H. Dine, F.R.S.

trough, it would move straight through just as if the liquid were not rotating and would pass through the centre of the trough.

A sphere, however, under the same conditions should be deflected and should pass to one side of the centre.*

The next prediction was that if any small or slow motion be communicated to a rotating liquid it must take place in two dimensions only. A consequence of this is that if you start a small motion in a rotating liquid and then put in a drop or two of coloured liquid to mark it as it moves, the coloured liquid will be drawn out into sheets which are everywhere parallel to the axis of rotation. These sheets when seen by anyone looking along the axis of rotation should appear as lines, and if the liquid does move in the way predicted by theory, a photograph taken by a camera on the axis of rotation will show the colouring matter spreading out as a thin line, instead of the usual irregular diffusion which happens in a non-rotating liquid. In Fig. 6 such a photograph is shown.

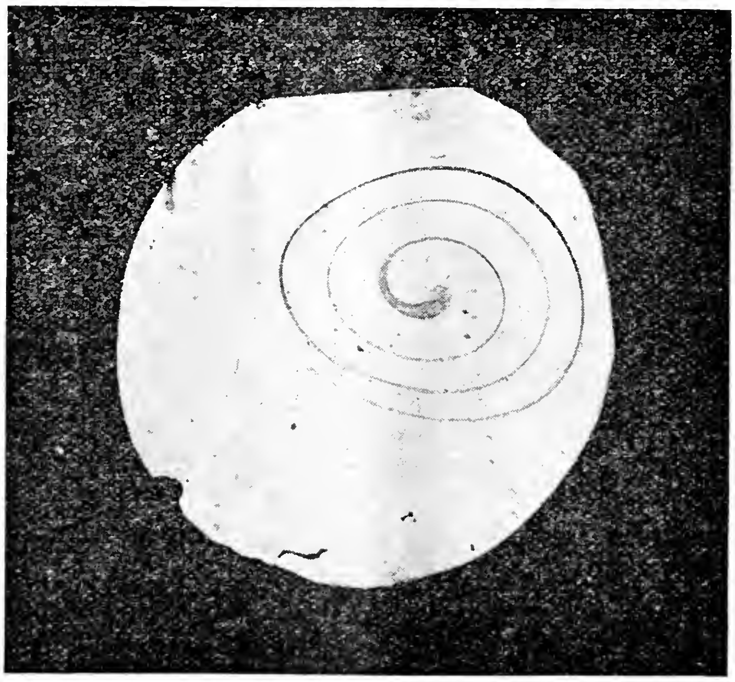


FIG. 6.—*Photograph of thread of coloured liquid in a rotating liquid, showing extreme thinness of the sheets into which the coloured liquid is drawn.*

It will be seen that this prediction also is completely verified.

The fact that the prediction that small motions in a rotating fluid are two-dimensional was so completely verified naturally led me into the inquiry: If the boundaries of the fluid move in such a way that the motion of the liquid cannot be two-dimensional, what happens? The answer must be that in this case the motion cannot be small everywhere.

I don't want to take up your time in pursuing the ramifications of this subject, but one result which came out has perhaps an important bearing on the foundations of aerodynamics. I solved the equations to the motion of a sphere moving uniformly along the axis of a rotating fluid. The equations which I used were the ordinary hydrodynamical ones which allow the fluid to slip over the surface of the sphere. One would expect therefore *à priori* that the results

* Two slides were shown illustrating these points. They are not here reproduced.

would be quite as useless as they are in the case of a non-rotating fluid. However, when I came to work out from my equations how much slip the ordinary theory leads one to expect at the surface, I found the extraordinary result that in this case there is no slip at all provided that the sphere itself is not rotating. That is to say the sphere should carry with it a sort of envelope or sheath of liquid which is not rotating or slipping past it.

In this special case, therefore, you will see that the circumstance which prevents the ordinary equations from representing the motion has disappeared, and there is a reasonable chance that they will, for the first time on record I believe, really represent the motion of liquid when a solid body moves in it.

It is difficult to devise any method for showing up the motion of a liquid in this case, but there is one prediction from theory which it should be easy to verify. If the non-rotating sheath predicted by theory really exists, then the sphere should move without rotation. If the sphere, originally rotating with the liquid and at rest relatively to it, begins to move along the axis of rotation, it should stop rotating, and should only start rotating again when it stops moving along the axis. This prediction also is verified. (The apparatus was shown and the experiment successfully performed.)

Conditions Favourable for Research.

I have tried this evening to bring into prominence the differences between the methods used in pure and applied science. It would be a pity to leave the subject without some reference to the conditions under which the various types of research work can most favourably be carried on, or suggesting how these conditions affect the possibilities of organising research.

Perhaps the most striking feature of aeronautical research at the present time is the large development of the use of models which has taken place during the last few years. Almost every change in design is now tested first in a wind tunnel.

With the rapidly increasing number of tests with which our wind tunnels have to cope, their staffs have increased and their methods have become standardised to such an extent that they are now large departments employing perhaps 50 or 60 people. The chiefs of these departments are good scientific men, but the success of the larger part of their work, which is routine work, will depend more on their organising ability than on their scientific attainments.

When we visit the National Physical Laboratory, the Royal Aircraft Establishment or the American National Aeronautical Laboratories we find magnificently equipped laboratories and highly trained staffs who are full of enthusiasm for scientific research. Their work is admirably organised, so that the wind channels are very seldom out of use, and every member of the staff has his time fully occupied from 9 to 5, or whatever their hours of business happen to be. It is difficult to see how more tests could possibly be carried out with the means at their disposal, or how they could be done better.

On the other hand it is by no means certain to my mind that the kind of organisation which is most suitable for routine test work is also the most suitable for scientific research.

To the unscientific visitor, an administrative officer or cabinet minister for instance, there is no difference between them. In both cases use is made of the same material, wind channels and instruments, and both are done largely by the same young men. There is, however, a vast difference between the calls which the two types of work make on the minds of the experimenters.

Tests, it seems to me, consist of a series of operations which a properly trained man can do at any time he is called upon, provided he is in sound physical health. They are usually intended to give numerical information about some

particular feature in design, and the form in which the answer will appear is known beforehand. In many cases the report on the test could almost be printed off beforehand, blank spaces being left for filling in figures. The time taken to do a test can be estimated by an experienced man as so many man-hours. Any tester who happens to be vacant at the time can be put on to a job, and the organisation of an establishment devoted to tests presents much the same problem to its chief as that of making up a railway timetable, or organising a machine shop.

Scientific research, on the other hand, is a very different matter. One is seeking for a principle, an explanation, or perhaps only the best shape for a part of a design, but the essential characteristic is that one does not know beforehand the form in which the answer is going to appear. One cannot estimate beforehand how long it will take. It occupies one not only from 9 to 5, but also from 5 to 9. I don't mean, of course, that one must work at it for the whole 24 hours, but that one's mind will keep going back to it at all times of day and night. One may work for weeks at it without a vestige of result, and then the result may come to one in the middle of the night, or during a chance conversation with a friend. It is even more likely that one may work for weeks or even months at a subject, never get any way with it at all and finally give it up with absolutely nothing to show for one's labours. Again, one man may do as much in a week as another in a month and may tire himself more during his more concentrated effort.

For these and other reasons, it seems to me that it is a problem of almost insuperable difficulty to organise an establishment for research on the man-hour principle. As to how it can be organised, I have no suggestions to offer. I can only say that in my opinion research work is so difficult and exacting that a man can only turn out his best work if he is completely free to go where his researches lead him, free to choose his own time for work, free from other duties which would divide his mind, and lastly, free to sit down and produce no visible result for weeks on end.

Under these conditions the applied scientist should, if he is a good man, make steady progress towards his goal. On the other hand, for the reasons I have already discussed, the pure scientist might make no progress at all in the direction towards which he set out. If he is a good man he will make progress in some direction or other, but that direction may not be one in which the particular institution which employs him has any interest.

The man who is doing research in applied science presents a difficult problem for the organiser, but the pure scientist is still more difficult to fit in, unless the institution which employs him is prepared to accept work covering a very large field indeed.

For this reason it seems that an institution which exists in order to further any particular applied science cannot employ a pure scientist so efficiently as an institution like a University or like the Department of Scientific and Industrial Research, whose interests cover the whole range of science.

Conclusion.

I expect that some members of the audience will be disappointed in a lecture about aeronautics which tells them nothing about aeroplanes. To the scientist an aeroplane is merely a complex body moving through a fluid, and until he understands how a simple body moves he has no chance of understanding the fundamental principles of aeronautics. I have chosen my examples of scientific methods in aeronautics for their merits as good illustrations of these methods, and for their novelty rather than for their usefulness in the practice of aviation.

If I have succeeded in producing in the minds of people engaged in the

administrative and practical side of aeronautics some idea of the difficulties encountered by the pure scientist in his search for fundamental principles, some idea of the way in which these difficulties react on his work, broadening his outlook and forcing him into several fields of science, and finally, if I have conveyed any idea of how important freedom is to him in order that he may carry out his best work, I shall feel that I have not spoken in vain.

THE PROBLEM OF FLAPPING FLIGHT.

BY HERBERT CHATLEY, D.SC. (ENGRG.) LOND., M.INST.C.E.I., ASSOC.M.INST.C.E.,
ASSOCIATE FELLOW.

It is only within the last few decades that it has been possible to conceive of a flying machine operating on the flapping system which would be consistent with mechanical principles. The development of gliding or "wedge" flight through the medium of the screw-propelled aeroplane has largely contributed to this result, but it must not be overlooked that as far back as 1899 Prof. Maurice Fitzgerald (Trans. Roy. Soc., Vol. LXIV., p. 420, and also (A) Vol. LXXXIII., p. 72, 1909) and Rayleigh (Manchester Lit. and Phil. Soc., Vol. XLIV., Pt. 2, No. 5, pp. 1-26—see Appendix III. hereto) enunciated certain of the most important factors of the problem. Whether the mechanical action should be the same as that of a bird is a matter for discussion, but anyway it is certain that a moving surface having a periodic vertical motion and a periodic change of "attitude" can efficiently produce lift and propulsion. The success of several rotary feathering lifting wheels (*e.g.*, Clarkson's and Pichou's, concerning the latter see "L'Aerophile," March 1st, 1912) in producing appreciable lifts per horse-power is significant, but it is probable that the inventors have not sufficiently realised:—

(1) The changes in relative motion which will occur during horizontal translation, and

(2) The increase of lift available during the acceleration of a flapping wing.

In a short article (partially based on Fitzgerald's and Rayleigh's papers, supplemented by a consideration of the effects of "attitude") contributed by the author to the Junior Institution of Engineers ("Journal," April, 1909, reprinted in "Fly" (U.S.A.), March, 1912, and appended hereto as Appendix I.), the first question is to some extent dealt with. The second forms the subject of Fitzgerald's later paper (1909).

Further complications will arise from the vertical motions of the body of a machine due to the periodic variation of the lift above and below its mean value (which is equal and opposite to the total weight), but it is probable that the vertical velocities so developed will be small under well arranged conditions.

Let it be supposed that a flapping wing machine possesses a forward horizontal velocity with respect to the air of 60 feet per second and that it is sustained by a flapping wing having a vertical range of 4 feet and a periodic time of one-fifth of a second. Further, let it be supposed that the displacement of the wing with respect to its mean position (on the body) varies harmonically. Then the vertical velocity of the wing with respect to the body is $V \cos \theta$, where

$$\theta = 2\pi \, t/T,$$

t being the period since the beginning of the stroke cycle and T the periodic time. The mean vertical velocity is 40 feet per second and the maximum velocity is 62.8ft. per second.

Neglecting the oscillations of the body, the relative velocity of the wing to the air at any instant is

$$\sqrt{\{ 60^2 + (62.8 \cos [10\pi t])^2 \}}$$

and the direction thereof is inclined to the path at an angle

$$\tan^{-1}\frac{62.8 \cos [10\pi t]}{60}$$

(Note that this has a maximum value of about 45°, which is, according to Pettigrew, the angle of maximum wing twist in flying animals.—Proc. Roy. Soc., 1866.)

If, during the downstroke, the angle of attack (chord of wing to relative air motion) be constant (say 5 degrees) and during the upstroke the said angle is zero, it will be found that an appreciable lift and propulsive force are developed. The calculation is best made by finite differences or graphical interpolation and planimetry.

Instead of a constant angle of attack, alternating with zero, a periodic change of "attitude" from six degrees to zero will give good results, as the table below will show.

In this table it is assumed that

(1) The reaction varies as the square of the relative velocity and as the angle of attack *plus two degrees.*

(2) The resultant acts one and a half degrees *ahead* of the normal to the chord.

This indicates that the lift during the half cycle of descent of the wing from the mid-position and the reascent to the mid-position varies from 45/24 to $10\frac{3}{4}$/24 of the mean value and that the drift is propulsive and can overcome a mean resistance equal to one quarter of the mean value of the lift, *i.e.*, one quarter of the weight supportable as a similar result is obtained in the other half of the cycle.

It will, of course, be understood that the analysis given is only approximate and intended for illustration. The researches of Eiffel, Riabouchinski, and others indicate the reactions in a steady stream to be of the order given, but it is somewhat doubtful what effect the accelerations and rotations will have. The relative velocity of the wing to the air changes periodically and it is uncertain whether the conformation of the streamlines will be the same at any instant of the cycle as that which would occur with a steady velocity identical with the instantaneous velocity. The presence of a "virtual mass" of fluid during acceleration necessarily implies some modification so that while the reaction will be quantitatively changed by the addition or subtraction of the product of the virtual mass into the acceleration, the actual aerodynamic effect may also differ. Bryan's rotative coefficients come into the question and when comparing with an aerofoil moving in a steady stream it should be remembered that the root mean square of the velocity is more important than the mean.

Further, it must be remembered that the acceleration alternately upwards and downwards of the whole mass will affect the problem. It is doubtful whether the vertical velocities of the body will attain values having any appreciable effect on the relative velocity, but the angle of attack being small may be so modified to an extent which will alter the reactions. If, for example, the sustaining force during the upstroke were zero, during rather more than half a cycle the body will be accelerating downwards under the force of gravity. Supposing, roughly, that the downward velocity during a half cycle alone needs to be considered, then its maximum value is $\frac{1}{2}gT$ where T is the periodic time. (Thus, if T is 0.2 seconds, the maximum downward velocity is 3.2 feet per second. If the forward velocity is 60 feet per second, this makes a difference of approximately 0.05 radians or say three degrees in the attitude of the wing.)

TABLE SHOWING LIFT AND DRIFT ON AN OSCILLATING WING; RANGE 4 FEET; PERIODIC TIME $\frac{1}{5}$ SECOND; HORIZONTAL MOTION 60 FEET PER SECOND; ANGLE OF ATTACK VARIES FROM 6° TO 0°.

Epoch in Cycle.	$V. \cos\theta$	$\tan^{-1}\left(\frac{V. \cos\theta}{60}\right)$	Angle of Attack γ	Wing Angle.	Direction of Resultant.	Lift Co-efficient.	Drift Co-efficient.	$60^2 + V^2 \cos^2\theta$	$\gamma + 2°$	Product.	Arbitrary Units. Lift.	Mean Lift.	Drift.	Mean Drift.	Remarks.
O	− 62.8	− 46° 10′	+ 6	− 40° 10′	48° 20′	0.7470	0.6656	7544	8°	60352	45	42	40	35	Midpoint.
T/12	− 54.4	− 42° 10′	+ 5½	− 36° 40′	51° 50′	0.7863	0.6189	6559	7½	49192	39	33	30	26	Wing descending.
T/6	− 31.4	− 27° 40′	+ 4½	− 23° 10′	65° 20′	0.9087	0.4184	4586	6½	29802	27	22½	12	5¾	
T/4	± 0	0	+ 3	+ 3	91° 30′	0.9997	−0.0262	3600	5	18000	18	18	− ½	− 5¼	Bottom of Stroke.
T/3	+ 31.4	+ 27° 40′	+ 2½	+ 30° 10′	118° 40′	0.8774	−0.4807	4586	4½	20667	18	17½	−10	−12¼	Wing ascending.
5T/12	+ 54.4	+ 42° 10′	+ 1½	+ 43° 40′	132° 10′	0.7412	−0.6721	6559	3½	22956	17¼	14	−14½	−12½	
T/2	+ 62.8	+ 46° 10′	0	+ 46° 10′	134° 40′	0.7112	−0.7037	7544	2	15088	10¾		−10½		Midpoint.
										Average		24		6	

NOTE.—The second half of the cycle, wing ascending from the midpoint and descending to it again, is the same as the above but in *reverse* order.

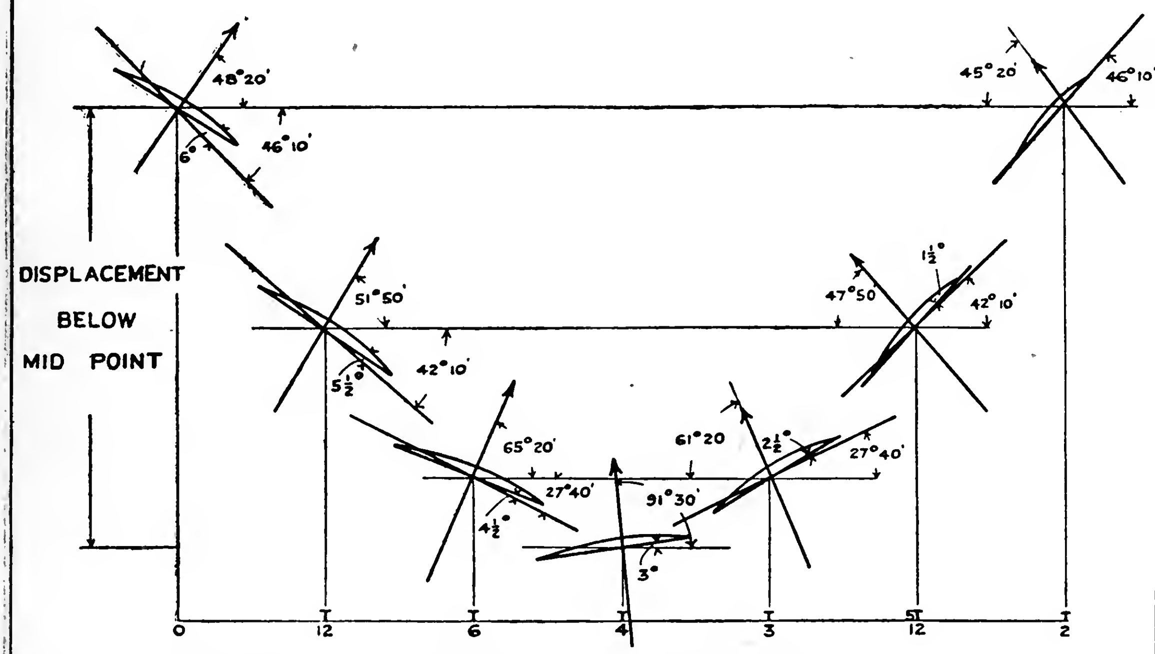


Fig 1. VARIATION OF DIRECTION OF REACTION DURING HALF CYCLE.

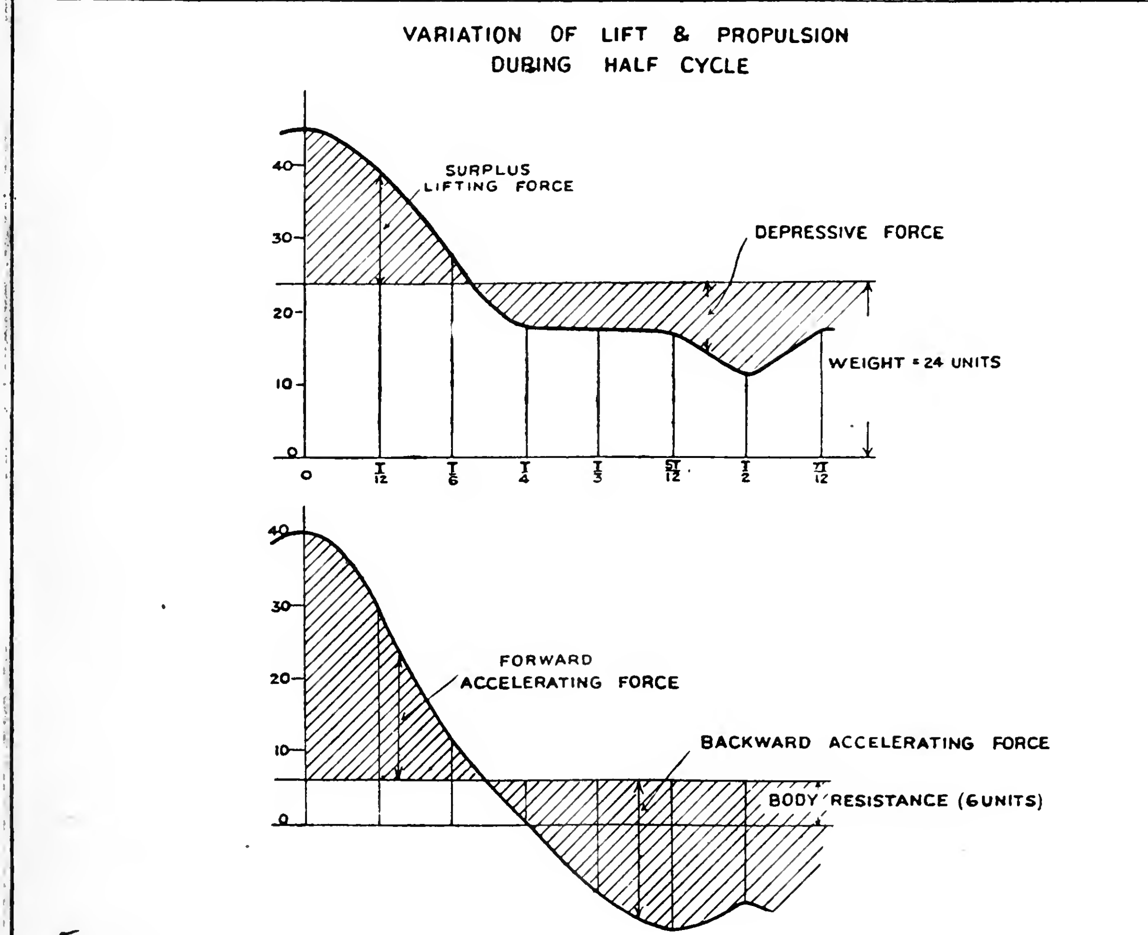


Fig 2.

The mean resultant of the forward thrust, as computed in the manner given above, has to overcome the body resistance only and as for good gliding conditions the body and wing resistance should be equal and the total resistance not more than one sixth the weight, it is not absolutely necessary that the said resultant should have a mean value more than one twelfth the weight. In any case, however, there is a periodicity in the value of the thrust with *negative* (backward) values during the upstroke (unless lift is sacrificed) so that the body will be subject to an alternate acceleration and retardation. In view of the fact that the mean thrust is but a fraction of the weight and the range of variation is not very great, the changes of velocity so produced will be less than the vertical changes so that when the velocity of translation is appreciable the effects of this horizontal variation can only be very small.

A careful study of the problem on the above lines clearly indicates the possibility of constructing an ornithopter. The mechanical difficulties remain to be considered. Two wing motions are necessary—

(1) A vertical linear reciprocation.
(2) An angular reciprocation.

These two need to be in "phase" and moreover must occur at the prescribed rates. The attainment of the latter result is not very easy. In view of the greater resistances during the downstroke there will be a tendency for this to occupy more than half the periodic time, the upstroke being correspondingly reduced. While this is of itself an apparent advantage it must be remembered that such a change from the hypothetical conditions involves alterations in the direction of relative motion. For this reason it would seem necessary that the vertical reciprocation should be produced by a "slider-crank" transmission from a rotating shaft with a flywheel or some other energy reserve to maintain regularity during the cycle. The torsional oscillation could be produced by a rigid transverse shaft through the wing rotated by gear wheels actuated by the vertical slider or by means of warping wires running over pulleys mechanically connected to such gear wheels. Whether the wings should rock on a fulcrum attached to the body (as with birds where it is a physiological necessity) or rise and fall in toto must be left to the designer to decide (see Appendix II.).

Three important questions must next be discussed:—

(1) Starting.
(2) Alighting.
(3) Stability.

Starting.

If the velocity of translation be omitted in the calculations indicated above, the angles of attack become very large, and without wishing to make any final pronouncement on the subject, the author should imagine the appliance would accelerate upwards and forwards until the conditions of equilibrium prescribed are attained.

An elevator such as is employed in aeroplanes would probably serve to determine the level at which horizontal flight should commence. Ascent, of course, implies extra power, but since the velocity of translation during ascent is less, a comparatively small reserve of power should prove sufficient.

Alighting.

If the mechanism is stopped and the wings locked in a proper position, descent by volplane will be possible. A few flaps just before contact with the ground should damp out the vertical velocity so that the impact may be small.

Stability.

The structure of a bird seems to indicate that the general principles of stability in the case of an aeroplane apply also to the ornithopter. There are, however, two further possibilities to consider:—

(1) Cumulative disturbance due to synchronism of the reciprocation with the natural oscillation of the appliance considered as a glider.

(2) Similar synchronism of the reciprocation period with that of gusts.

The necessity of avoiding such synchronisms clearly leads to the adoption of a very short period for the reciprocations. Few birds make less than five beats per second and probably this is about the minimum number desirable. Gusts rarely have a periodic time of less than one second and more generally take from five to ten seconds to complete a cycle. As to the natural oscillations, it will be necessary to compute these in accordance with the Bryan theory and take precautions to assure a difference between these and the reciprocation period.

The above notes were written before the war, but nothing has since happened seriously to invalidate the figures. The mechanical argument is apparently unassailable. The difficulty lies in the mechanism required.

APPENDIX I.

From "Fly Magazine."

APPLICATION OF THEORY TO ORNITHOPTERS.
THE ACTION OF THE FLAPPING WING.

BY HERBERT CHATLEY, B.SC. (ENG.), A.M.I.C.E.I.,

PROFESSOR OF CIVIL ENGINEERING, TANG SHAN IMPERIAL ENGINEERING COLLEGE.

The essential feature of the ornithopter is the reciprocating motion of the supporting surfaces. A study of bird flight shows that in nearly all cases ascending flight is performed by reciprocating motion, horizontal flight by reciprocating motion in most cases, and descending flight almost always by gliding. The wings therefore act to some extent in the same manner as the "aerofoils" of a gliding machine, and it may be true (as most aeroplanists assert) that with a continuous means of propulsion (the propeller) gliding flight is mechanically preferable in all cases. Nevertheless there is the great advantage in bird flight that no great initial velocity is required, and there is no loss of energy due to an indirect means of propulsion. Hence there still exists a large class of would-be aviators who believe in the flapping type.

The researches of Borelli, Pettigrew, Marey and Mouillard have supplied much information as to bird flight, but no exact knowledge was obtained until Marey made his cinematographic and sphygmographic observations. It then appeared that the wing twisted during reciprocation (see diagrams in my book, "The Problem of Flight," Chap. III.), and it immediately became conceivable that the wing acts as an aerofoil does, and not with a simple beating action. It is difficult to see, if the wing does not twist, how the difficulty of the down thrust on the upstroke can be prevented.

Lord Rayleigh in his famous paper to the Manchester Literary and Philosophical Society, in 1900, gave a tentative mathematical analysis of bird flight, but does not seem to have definitely considered the "attitude" of the wing in the different points of its path, but the following investigation is on very similar lines to those suggested by him. As a matter of fact, I think that the aforesaid

paper shows a more general knowledge of the fundamental principles of flight than any work which has appeared until we reach Lanchester's book. Many of Lanchester's important conclusions as to friction and economics of flight are derivable therefrom, and most of us have been blind these few years.

The most important point in connection with the action of the wing is the direction of its motion relatively to the air. *This is not the same as that of the body*, but differs therefrom by a certain angle. If the vertical velocity of reciprocation of one point of the wing at a certain time is v, and the body has a horizontal velocity V, then the wing is proceeding in an inclined direction upwards or downwards (according as v is upwards or downwards), the inclination being

$$\theta = \tan^{-1}\frac{v}{V} \qquad . \quad . \quad . \quad . \quad . \qquad (1)$$

with the horizontal.

In order to simplify the mathematical treatment of the subject I will make the following preliminary assumptions:—

(1) That the wing is an aeroplane. This is quite untrue in the case of birds, but we can modify it to suit aerocurved surfaces afterwards.

(2) That the reciprocation is wholly vertical. This is also untrue, since the wing swings about its root in an arc, but, as the horizontal component of the velocity at each position in symmetric flight will neutralise that on the other wing, it is only necessary to find the point on the wing at which there is the mean effective velocity, in order to convert from that velocity to angular velocity of the wing about its axis in the root.

(3) That this vertical velocity of reciprocation varies harmonically throughout the cycle, and that the "attitude" of the wing similarly varies, but not necessarily in the same phase.

(4) That the line of flight is horizontal.

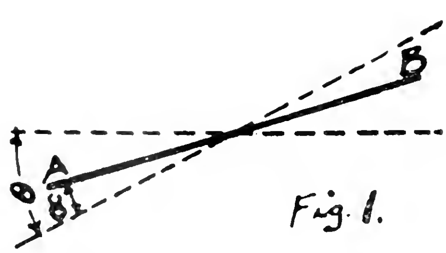


Fig. 1.

The diagram Fig. 1 represents the aeroplane $A\ B$ in section, with a forward horizontal velocity V and a downward velocity v. The actual velocity in still air will then be

$$U = \sqrt{(v^2 + V^2)} \qquad . \quad . \quad . \quad . \quad . \qquad (2)$$

The angle of attack (*i.e.*, the angle between the aeroplane and the direction of relative motion) is α, and the reaction on the surface is then

$$N = KAU^2 \sin \alpha \qquad . \quad . \quad . \quad . \quad . \qquad (3)$$

There will be a vertical and upward component

$$L = N \cos(\theta - \alpha) \qquad . \quad . \quad . \quad . \quad . \qquad (4)$$

and a horizontal and forward component

$$T = N \sin(\theta - \alpha) \qquad . \quad . \quad . \quad . \quad . \qquad (5)$$

In order to express the position of the plane with reference to the axis of the body (in this case horizontal) I will call $(\theta - \alpha) = \beta$, so that $\alpha = \theta - \beta$.

It should be observed that T here acts as a propelling force, and is opposed by a frictional resistance depending on the form and area of the wings and body, and to a very slight extent, on the position of the wing. We will call this resistance R. Under conditions of turbulent motion

$$R = \mu V^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

The vertical component of this resistance will be negligible.

Hence the vertical equation of motion is

$$M \frac{d^2 z}{dt^2} = Mg - KAU^2 \sin(\theta - \beta) \cos\beta \quad . \quad . \quad . \quad (7)$$

and the horizontal equation of motion is

$$M \frac{d^2 x}{dt^2} = \mu U^2 - KAU^2 \sin(\theta - \beta) \sin\beta \quad . \quad . \quad . \quad (8)$$

These are not integrable equations because U and β are unknown functions of the time.

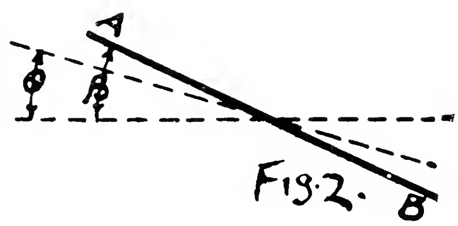


Fig. 2.

Fig. 2 represents the wing ascending and the notation employed above can be again used. *In this case, however, the reaction cannot produce a forward component.* For β being greater than θ there is a lift, but the reaction is directed backwards, and the horizontal component will cause considerable retardation.

If θ is greater than β then there is a reaction on the upper surface and the wing is subject to a down thrust. Even if this were permissible to a slight extent the forward component would not be appreciable without a very considerable down thrust.

Hence we see that values of β either greater than or less than θ are aerodynamically objectionable, and we have the conclusion that $\beta = \theta$ during the upstroke.

This condition will not necessarily apply when both θ and β are very small, since then the resistance due to an excess of β over θ would not be very appreciable, and the prolongation of the lift would be useful. Furthermore, in the case of aerocurves the reaction is directed somewhat a little forward of the normal, so that with such aerocurves a small excess of β over θ when both are small would not necessarily cause any aerodynamic resistance.

Reverting now to the downstroke we see that in order that this should be most effective the ratio of the thrust to the lift should be maximum. This depends on both β and θ, and is identical with the ordinary problem of gliding. There are two criteria for the value of $\theta - \beta$ (the angle of attack) :—

(1) It should be about 6° for an aeroplane (Lanchester, Ferber).
(2) It should be about half the gliding angle θ (Penaud, Ferber).

Employing the first condition we see that when the velocity of reciprocation is a maximum (*i.e.*, θ is a maximum)

$$\theta - \beta = 6° \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

Given the maximum velocity of reciprocation v_1 we have then a means of finding the two maximum values of β. On the upstroke it has been shown that $\beta = \theta$. Hence we have

$$\beta_1 = \tan^{-1} \frac{v_1}{V} \qquad \text{(10)}$$

and on the down stroke

$$\beta_2 = \tan^{-1} \frac{v_1}{V} - 6^\circ \qquad \text{(11)}$$

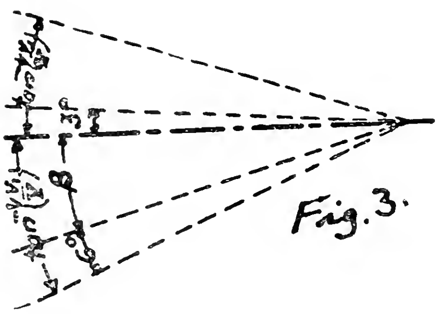


Fig. 3.

These conditions can be satisfied if we suppose that β varies harmonically in the same phase as v from a value of 3° to a range of

$$\tan^{-1}\left(\frac{v^1}{V}\right) - 3^\circ$$

above and below this (see Fig. 3).

Hence expressing v and β as functions of the periodic time τ we have

$$v = v_1 \sin\left(\frac{2\pi}{\tau} t\right) \qquad \text{(12)}$$

and

$$\beta = 3^\circ + \sin\left(\frac{2\pi}{\tau} t\right) \left\{ \tan^{-1}\left(\frac{v^1}{V}\right) - 3^\circ \right\} \qquad \text{(13)}$$

so that we have the following table of values :—

	Epoch. $\frac{2\pi}{\tau} t$	Velocity. v	Attitude. β
Beginning of upstroke or end of downstroke ...	$0\ (\tau = 0)$	0	3°
Middle of upstroke ...	$\frac{\pi}{2}\ (\tau = \frac{1}{4})$	v^1	$\tan^{-1}\left(\frac{v^1}{V}\right)$
End of stroke	$\pi\ (\tau = \frac{1}{2})$	0	3°
Middle of downstroke ...	$\frac{3\pi}{2}\ (\tau = \frac{3}{4})$	$-v_1$	$-\tan^{-1}\left(\frac{v^1}{V}\right) + 6^\circ$

Marey's diagrams may be tested by comparing the values of β given in formulæ 10 and 11, with his diagrams of the wing cycle ("Le Vol des Oiseaux," "Animal Mechanism," and my own book, vide Suprâ). The agreement is fairly close.

It should be observed that the quantity v_1 is involved. As far as I recollect the maximum values of β are about 25°, so that $\tan^{-1}(v_1/V)$ equals about 20°, and v therefore equals 0.36 V. This will be the velocity of a point about $\frac{2}{3}$ the length of the wing from the root.

In correcting for pterygoid section it is necessary to note that the reaction is inclined about 2° or 3° forward from the normal to the chord of the curvature, so that the resistance is decreased. This correction will more particularly apply to the resistance question considered below.

On the Lift and Horizontal Force in Relation to Weight and Head Resistance.

I have given above formulæ relating to the lift and horizontal component of the aerodynamic reaction, but it is necessary to average these with regard to time throughout one cycle in order to find if the weight and resistance can be balanced.

By formulæ 3 and 4 the lift is

$$KAU^2 \cos\beta \sin(\theta - \beta)$$

which, noting that v varies harmonically, is equal to

$$L = KA\left\{V^2 + v_1^2 \sin^2\left(\frac{2\pi}{\tau}t\right)\right\}\cos\left[3^\circ + \sin\frac{2\pi}{\tau}t\left\{\tan^{-1}\left(\frac{v^1}{V}\right) - 3^\circ\right\}\right]$$

$$\times \sin\left\{\tan^{-1}\left\{\frac{v^1 \sin\left(\frac{2\pi}{\tau}t\right)}{V}\right\} - \left[3^\circ + \sin\left(\frac{2\pi}{\tau}t\right)\left\{\tan^{-1}\left(\frac{v^1}{V}\right) - 3^\circ\right\}\right]\right\} \qquad (14)$$

and a similar substitution may be made for T_1 the thrust.

These forms do not appear to be integrable, but from the nature of the problem they can have no appreciable value during the first half of the cycle.

To apply them to any particular case they must be calculated for several positions during the downstroke, plotted to a time base and their average value so obtained. Let these averages value L_0 and T_0 for the half cycle. Then the averages for the whole cycle will be $L_0/2$ and $T_0/2$, and for steady flight we have

$$L_0 = 2W \qquad (15)$$

$$T_0 = 2R \qquad (16)$$

Roughly these quantities will vary harmonically through the hemi-cycle of the downstroke, for the difference between θ and β varies harmonically on account of the simultaneous harmonic variation in these quantities. The resolution of the vector with regard to β will, however, prevent this from being exact, as well as the initial value of β, and the variation in the relative velocity.

If we however assume a harmonic variation in the lift and thrust then the averages throughout the whole cycle will be $1/\pi$ times the maximum values.

The maximum values are

$$L_{max} = KA(v_1^2 + V^2)\sin 6^\circ \cos\left(\tan^{-1}\frac{v_1}{V} - 6^\circ\right) \qquad (17)$$

$$T_{max} = KA(v_1^2 + V^2)\sin 6^\circ \sin\left(\tan^{-1}\frac{v_1}{V} - 6^\circ\right) \qquad (18)$$

As a very rough approximation we might say that

$$L_{\max} = \pi W$$
$$T_{\max} = \pi R$$

for steady flight.

As regards the possibility of constructing machines on the ornithopteric principle, it is fairly clear that the chief difficulties lie in the question of timing and adjusting the angle of attack, and I hope the above discussion of the aerodynamic action may render considerable assistance in this direction.

APPENDIX II.

There is undoubtedly some particular form of wing which will be most efficient under given conditions of beat and twist; with a given wing there must be some special relation of twist to beat which gives the best results. From analogous cases in machinery it may be safely concluded that the variation of the thrust and lift from mean values should be as small as possible (except in so far as "virtual mass" may be valuable) and that the quantity of fluid handled should be a maximum. It is also fairly certain that there can be only one speed of horizontal translation for any one wing which will give highly efficient working. Increased rates of reciprocation may, of course, render it possible to travel at a higher speed, but the normal conditions should be those of maximum efficiency. In addition it would seem desirable that this "normal speed" should be the same as the normal gliding speed considering the machine as an aeroplane so that easy transition from flapping to gliding can occur.

APPENDIX III.

LORD RAYLEIGH'S EXPOSITION OF FITZGERALD'S THEORY OF FLAPPING FLIGHT.

["Manchester Memoirs," Vol. XLIV. (1899), No. 5, pp. 24-5-6.]

"We denote by u the horizontal velocity of the plane supposed uniform, by v the vertical velocity at time t, by θ the inclination of the plane to the horizon at time t, while S and W denote the area and weight. If we assume the formula for the pressure, although the application is now to an *unsteady* motion, and further suppose that v/u and θ are always small, we get for the whole normal pressure upon the plane at time t

$$KS\,(u^2 + v^2)\,(\theta + v/u) \quad . \quad . \quad . \quad . \quad . \quad (40)$$

in which, however, v^2 in $(u^2 + v^2)$ may be omitted.

We now assume that θ and v are periodic, for example, that

$$\theta = \theta_0 + \theta_1 \cos pt \quad . \quad . \quad . \quad . \quad . \quad . \quad (41)$$

$$v/u = \beta \cos (pt + \epsilon) \quad . \quad . \quad . \quad . \quad . \quad . \quad (42)$$

where the periodic time τ is related to p according to

$$\tau = 2\pi/p$$

At this stage criticism may present itself that the assumed motion involves a reaction for which we have made no provision. In practice the reaction is

supplied by the inertia of the body of the bird to which the wings are attached. The difficulty would be got over by supposing that there are several planes executing similar movements, but in different phases regularly disposed. It seems hardly worth while to complicate the present investigation by introducing a vertical movement of the weight.

By (40) the whole pressure at time t, perpendicular to the plane is

$$KSu^2 \{ \theta_0 + \theta_1 \cos pt + \beta \cos (pt + \epsilon) \} \quad . \quad . \quad . \quad (43)$$

Of this the mean value is to be equated to the weight W supported, so that

$$W = KSu^2\theta_0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (44)$$

The horizontal component of the whole pressure at time t is

$$S \;.\; Ku^2 \{ \theta + v/u \} \theta \quad . \quad . \quad . \quad . \quad (45)$$

and of this the mean value is to be supposed to be zero, in order that the plane may move with uniform horizontal velocity.

Thus

$$\theta_0{}^2 + \tfrac{1}{2}\theta_1{}^2 + \tfrac{1}{2}\beta\theta_1 \cos \epsilon = 0 \quad . \quad . \quad . \quad . \quad (46)$$

Again, if WU be the (mean) rate of expenditure of work

$$WU = S \;.\; Ku^2 \int_0^{\tau} (\theta + v/u)\, v d\,(t/\tau) = S \;.\; \tfrac{1}{2}Ku^3 \,(\beta\theta_1 \cos \epsilon + \beta^2)$$

$$. \quad . \quad . \quad . \quad . \quad . \quad (47)$$

If we eliminate β between (46) and (47), we get

$$WU = S \;.\; \tfrac{1}{2}Ku^3 \frac{(2\theta_0{}^2 + \theta_1{}^2)\,(2\theta_0{}^2 + \theta_1{}^2 \sin^2\epsilon)}{\theta_1{}^2 \cos^2\epsilon} \quad . \quad . \quad (48)$$

from which we see that if θ_1 be given (as well as SWu), U is least when $\epsilon = 0$, viz., when the phase of maximum vertical velocity coincides with the phase of greatest inclination. In this case, by the use of (44), we have

$$U = (W/KSu)\,(1 + 2\theta_0{}^2/\theta_1{}^2) \quad . \quad . \quad . \quad . \quad (49)$$

If we regard WSu as given, the smallest value of U corresponds to θ_1 being large in comparison with θ_0 which is given by (44).

(It must not be forgotten that θ_1 itself has been assumed to be small.)

The smallest value is

$$U = W/KSu \quad . \quad . \quad . \quad . \quad . \quad . \quad (50)$$

The work required to be done is here the same function of SW and the horizontal velocity as was found in the case of the aeroplane.

We see from (46) that, under the circumstances supposed, $\theta_1 + \beta$ is numerically small in comparison with θ_0, and *a fortiori* in comparison with θ_1. Accordingly the forward edge of the plane is inclined downwards when the motion of the plane is downwards.

As regards the pressure, it is by (43) proportional to

$$\theta_0 + (\theta_1 + \beta) \cos pt$$

in which the second term is relatively small. The pressure acts always upon the under side of the plane, and the weight is approximately supported in all phases."

[The only serious comment which can be made on the above remarkable analysis is that (1) friction should not be neglected, and (2) in practice the maximum value of v is quite comparable with u so that the approximations assumed need to be modified as has been done in the numerical example worked out in my paper.—H.C.]

REVIEW.

Non-Ferrous and Organic Materials. Arthur W. Judge. Sir Isaac Pitman and Sons, Ltd. 25s.

This book will be found a useful one for reference. It is largely a compilation of published data rather than an account for personal experience. It contains much useful data, but it covers rather too wide a field to adequately deal with some of the subjects discussed. It will, however, be found useful as giving an idea of the properties of the various materials. The earlier chapters deal with non-ferrous metals. Chapter V. contains a useful and effective account of the classification and examination of different types of timber, whilst Chapter VI. gives an account of the tests to be applied to timber for the purpose of ascertaining its suitability for specific purposes. Chapter VII. is devoted to a description of tests applied to aircraft fabrics and coverings. The subject of dopes and varnishes for use in aircraft construction is dealt with as well as the space in Chapter VIII. permits. The handling of the chemical side of the preparation of dopes and varnishes is scanty. Chapters IX. and X. deal with glues and rubber in a useful manner. In the 27 pages of Chapter XI., devoted to paints and painting, the Author has succeeded in giving a useful resumé of the properties of pigments, oils and dryers and the application of paints to surfaces.

A general impression left on the mind of the reader is that the Author has succeeded in producing a book containing useful practical information to those interested in this branch of industry. The large scope of the book further necessarily results in a lack of detail which is pronounced in certain parts, but the illustrations and tables of data are effective in making clear the matter presented in the volume.

THE

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Edited for the Council by J. LAURENCE PRITCHARD, Fellow.

All communications should be addressed to the Editor.

No. 130. OCTOBER, 1921. Vol. XXV.

Notices of the Royal Aëronautical Society.

Election of Members.

The following members were elected at a Council Meeting held on September 20th:—

Associate Fellows.—Wing Commander H. R. Busteed, O.B.E., A.F.C., Herbert Carrington, B.Sc.
Student.—G. Reid.
Member.—W. H. Tripp.

Paris Air Congress.

In response to an invitation received from the French Air Attaché, the Council have nominated the Chairman (Lieut.-Col. M. O'Gorman) and the Secretary to act as their representatives at the International Air Congress to be held in Paris during November.

Students' Discussion Meetings.

Dr. L. Bairstow presided at a meeting of students held at the Society's offices, on September 19th, when it was decided provisionally to hold meetings in the Library at 7.0 p.m., usually on the second Thursday in each month. These meetings will be for students only, with a member of the Society in the chair, and at each a discussion will be inaugurated by the reading of a paper by a student. These papers will be adjudicated upon by the Council at the end of the Session and the Pilcher Memorial Prize for Students awarded to the one which is considered to be the best. It was decided not to elect any officers for the Students' Section at the moment, with the exception that Mr. Stanley Evans was invited to continue to act as Honorary Secretary *pro tem.*

The following promises of papers were received:—

October 13th.—T. A. Kirkup on "A Comparison of Different Types of Aerofoils."
November 10th.—W. L. Le Page on "The Soaring Flight Problem."
December 8th.—Colin Daniel.
January 26.—S. R. Irvine.

All papers must be in the Secretary's hands at least three clear days before the date of reading.

Books Required.

The following books are urgently required for the Library. The Secretary will be very grateful if any member, who has spare copies of any of them, would be so kind as to present them:—

Chemistry.

"Rubber, Resins, Paints and Varnishes," R. S. Morrell and A. de Waele.
"Handbook on Sampling and Testing," Manchester Chamber of Commerce Testing Laboratory.
"La Cellulose," L. Clement and C. Riviere.
"Technology of Cellulose Acetates," Warden. Vol. VIII.
"Liquid Fuel for Internal Combustion Engines," Archbutt and Dieley.

Construction.

"Aeroplane Timbers," G. R. Keen.
"Strength of Materials," G. Morley.
"Theory of Structures," G. Morley.
"The Heat Treatment of Steels," H. Brearley.

Engines.

"Gas, Petrol and Oil Engines," Vols. I. and II., D. Clerk and G. A. Burls.
"Thermodynamics for Engineers," J. A. Ewing.

Meteorology.

"Manual of Meteorology," Part IV., Sir Napier Shaw.
"Forecasting Weather," Sir Napier Shaw.
"Principles of Aerography," McAdie.

REFERENCE BOOKS.

Chemistry.

"Dictionary of Applied Chemistry," Thorpe.

Light Alloys.

"Aluminium Alloys Reports," American Bureau of Standards.
"Light Alloys Committee Reports" (VII., IX. and XI.), Inst. of Mech. Engineers.

Books Received.

The following books and pamphlets have been received and placed in the Society's Library:—"A Text-Book of Aeronautical Engineering. The Problem of Flight" (3rd Edition), by Dr. H. Chatley; "Kite Balloon Winch Manual" (Air Publication 817); "An Introduction to Physics for Technical Students," by P. J. Haler and A. H. Stuart; "Who's Who in Engineering," by the Compendium Publishing Company.

Arrangements for the Month.

Oct. 5, 11.0 a.m. Special Meeting of Council.
,, 6, 5.30 p.m. Lecture by Air Commodore Brooke-Popham on "Aeroplanes in Tropical Countries," Royal Society of Arts, Adelphi, London.
,, 13, 7.0 p.m. Students' Discussion Meeting, T. A. Kirkup on "A Comparison of Different Types of Aerofoils."
,, 17, 8.0 p.m. *Scottish Branch.*—Lecture by Col. V. C. Richmond on "The Organisation of a Colonial Airship Service," Engineering Class Room, Glasgow University.

Oct. 18,	4.0 p.m.	Publications and Library Committee.
	4.30 p.m.	Candidates' Committee.
	5.0 p.m.	Council Meeting.
,, 20,	5.30 p.m.	Lecture by Mr. Griffith Brewer on "The Langley Machine and the Hammondsport Trials," Royal Society of Arts, Adelphi, London.
,, 31,	8.0 p.m.	*Scottish Branch.*—Lecture by Professor Gordon Gray on "Research Work on the Application of Gyroscopes to Aviation," Natural Philosophy Class Room, Glasgow University.

Members do not require tickets for lectures, but can obtain them for their friends on application to the Secretary.

W. Lockwood Marsh, *Secretary.*

R38 MEMORIAL FUND.

The following letter, signed by the President, has been sent to the Editor of "The Times." Donations towards the fund, for which a separate banking account has been opened, should be sent to the Secretary:—

28th September, 1921.

To the Editor of "The Times,"
Printing House Square, E.C.4.

Sir,

The Council of the Royal Aeronautical Society have decided to establish a Memorial Fund, to commemorate those who have been lost in R.38 and in previous airships, and to be called the "R.38 Memorial Fund."

It is proposed to invest the capital and devote the income to the encouragement of investigation into problems connected with airships or allied subjects, which course it is felt would best meet the wishes of the relatives of those who have given their lives in the cause of airships.

As is now well known, it has been decided to suspend all Government work on airships, and it is probable that little or no provision will be made for the continuance of experimental or research work. It is, however, of paramount importance that some such work should be proceeding, on however small a scale, pending the time when the resumption of an airship service is decided upon. A sufficient capital sum to provide an annual grant towards the carrying out of some specific investigation—on a large or small scale according to the amount available—would, it is felt, be a valuable aid during this hiatus, and the period of reconstruction following it, and would serve as some safeguard, even though perhaps a slight one, against the complete neglect of airship possibilities. It is proposed that the results of the investigation should be embodied in a paper or papers to be read before the Members of the Royal Aeronautical Society.

I therefore beg to ask you to grant me the hospitality of your columns to invite your readers to forward contributions to this fund to the Secretary, Royal Aeronautical Society, 7, Albemarle Street, London, W.1.

Yours faithfully,

(Signed) WEIR,

President.

SCOTTISH BRANCH.

ANNUAL MEETING.

The future of commercial aviation and the function of the British cross-Channel services in providing experience for the development of the industry were discussed by Lord Weir of Eastwood, President of the Royal Aeronautical Society, who presided at the Annual Meeting of the Scottish Branch of the Society, which was held in the hall of the Institute of Engineers and Shipbuilders on Monday, September 19th. The annual report, already published, was submitted by the Hon. Secretary, Mr. J. Buyers Black.

Lord Weir said it gave him great pleasure to be present and to move the adoption of the report, which reflected the greatest possible credit on the Scottish Committee and its noble Chairman, and on the work of their indefatigable Secretary, Mr. Buyers Black. It was with feelings of the deepest regret that he referred to the unique losses which their Air Force had had to bear. In the first case they had to lament the loss of one whom many of them knew and looked upon as the most knightly figure in their British aviation world, General Sir David Henderson. Many tributes had deservedly been paid to him. He was the first man, or at least the first soldier in Great Britain, to grasp in a practical manner the vast possibilities of aircraft as a weapon of war. To the progress of aviation he sacrificed an undoubtedly great future as a soldier, but he became the greatest influence and the greatest personality in British military aviation. He created the Royal Flying Corps, and later on he exercised a dominating influence in the creation of the Royal Air Force. That was not generally known, but it was the case. Almost coincident with General Henderson's death came one of the greatest disasters ever suffered by the Royal Air Force, the loss of the R38. The airship might be replaced, but the individuality and character of such men as Commodore Maitland and others was quite irreplaceable. They recalled that Commodore Maitland's last public appearance in the cause of aviation was in Scotland under the auspices of the Scottish Society, when on March 14th he addressed a meeting of public school cadets. The influence of the disaster on the immediate development of lighter-than-air craft could not be ignored. He (Lord Weir) was perfectly convinced that a very successful step was taken in asking the great Dominions and Colonies to take a share in the responsibilities of that decision. The future of the airship meant much more to those Dominions in every eventuality than to us in these islands.

Passing for a moment from the airships, any review of British aviation and of the progress made during 1921 would be quite incomplete if it did not embrace some reference to the situation in regard to heavier-than-air service across the English Channel. He had had the honour to be Chairman of the Advisory Committee on Commercial Aviation since the Armistice, and in the recommendations of that Committee, along with others, he had laid great stress on the necessity for concentration of effort on these services, because he believed that those services must offer the best opportunities for the display of British air transport enterprise anywhere in these islands. For those reasons he had consistently pressed the Air Ministry and the Government to offer the most encouraging possible conditions to British enterprise on the cross-Channel services.

Lord Invernairn seconded the adoption of the report. He said they were looking forward to a very interesting session. They would be interested to learn from the report that Glasgow would be one of the centres in which it was intended to move actively in the near future, and it was incumbent upon them to seize the opportunity offered Glasgow to take a first-hand interest in aviation. It was

gratifying to know that the Air Ministry had retained for the present, under a lease of five years, Renfrew Reception Park, and they might look forward before long to making some practical use of it for their students at the University. That was one of the subjects which would engage the attention of the Scottish Executive in the course of the next year.

The report was approved, and on the motion of Mr. Harold Yarrow, seconded by Sir John Reid, the Executive Committee were re-elected.

Progress in Canada.

A communication from Mr. Norman A. Yarrow, Victoria, British Columbia, on "Commercial Aviation in Canada," was read by Mr. Buyers Black. Mr. Yarrow, in the course of his Paper, said that in the development of commercial aviation the two watchwords must be "safety" and "reliability." There was a huge amount of survey work with the camera to be done by means of the air, together with the protection cruises of the forest against fire. Aircraft to-day in Canada was just as the automobile was fifteen years ago. In Canada there were 30 firms engaged in operating aircraft, and between May 1st and October 31st, 1920, 422,000 miles had been flown and 15,000 passengers carried. Taking into consideration that no aerial transport took place till after the signing of the Armistice, they had made a fair start.

THE MANŒUVRES OF GETTING OFF AND LANDING.*

BY SQUADRON LEADER R. M. HILL, M.C., A.F.C.

PART I.—INTRODUCTION.

1. General Remarks.

The manœuvres of getting off and landing are to me the beginning and the end of flight; they separate the sheep from the goats; the aristocrat of the flying world uses them for the display of his genius, leaving his would-be imitators to find what consolation they can in the amusement with which they innocently provide the onlookers.

In commercial flying the manœuvres of getting off and landing are still the most obvious calls on the pilot's skill; and who shall deny the splendid response? But a determination to ease the pilot's task is not thereby for an instant to be excused. This, one of the most urgent problems before applied design to-day, lies in the conflicting requirements of ease and safety in getting off and landing and those of economy and usefulness in full flight. To assist in the statement of this problem is the object of my Paper. These are the manœuvres perhaps about which most has been said, and, from the pilot's point of view, least written. Since first a heavier-than-air machine left the ground, they have never failed as a topic of conversation throughout the whole flying community; and this has tempted me to analyse them on the basis of my own experience and that of the many pilots I have known.

Theoretical analyses of these manœuvres, while endowing the assumed pilot with human characteristics, have of necessity to envelop in a hypothetical average the diverse individual variations. Yet, in practical flying, proximity to the ground in the neighbourhood of stalling point throws into stronger relief than at any other time human variations in handling. There are many classes of pilot in whose flying various degrees of intelligence and instinct are blended; and each class has its own way of meeting the difficulties and ensuring what it considers to be the maximum of safety. So it is difficult to make a sweeping generalisation. At the same time, almost independently of the quickness of a get off, or the slowness of a landing, it is possible to recognise in it what is termed good or bad style, something which can or cannot be identified with cleanness of handling, reliability and a sense of mastery.

The manœuvres of getting off and landing may be divided into two classes; firstly those under normal and satisfactory conditions, with reasonably good ground and sufficient space for the pilot to get off and land without taking into account any limitations save those of his aeroplane; and secondly what are termed forced manœuvres, manœuvres in which the pilot is limited in some way; for example, getting off in a confined space, over unnaturally high obstacles or on bad ground, or, after engine failure, judging a landing in an unknown field.

A forced landing with an aeroplane on which a pilot is experienced is frequently taken as the ultimate test of his powers of foresight, judgment and flying capacity; if then he is not quite at home on the particular type he is flying, his difficulties in forced manœuvres will be increased tenfold. Yet the pilot has even now, due to the imperfection of the aero engine, to face the possibility of a forced manœuvre on types with which he is unfamiliar before he has had the chance to become experienced on them; and so such manœuvres are worth all the study and preparation beforehand that he can possibly give.

* Lecture to be delivered before the Society, November 3rd.

2. The Nature of "Getting Off" and "Landing."

The manœuvre of getting off will be taken to commence with the opening of the throttle when the aeroplane is at rest, and to conclude with the condition of steady climb free from the embarrassing proximity of the ground; that of landirg to extend from the moment that the pilot is influenced by the necessity of approaching a definitely limited landing space, to the time when the aeroplane is again at rest on the ground.

When the pilot is about to take off the ground he realises that his craft is not supported by the element in which he is going to fly and manœuvre, but by its wheels and tail skid as it rests on the ground. From the moment he opens the throttle until his wheels leave the ground, the conditions of his support undergo a gradual translation, leading up, as it were, to the moment when he is completely air borne. During the translational period the aeroplane often shows characteristics alien to normal flight, which are apt to deceive the pilot as to what it is going to feel like in the air. Although the translation from ground to air conditions has been referred to as gradual, the process is further complicated because in practice the ground is rarely smooth enough to allow the pilot to get off without several bounces, which may disturb his well-laid plans. Neither can the pilot be said to have completed his getting off until he is climbing steadily well clear of the ground. As long as he is low down, the nearness of the ground exerts on his handling of the aeroplane a powerful influence, from which he cannot shake himself free until he is at least 1,000ft. up. The whole process of getting off may roughly be divided into *three phases*: that in which the aeroplane is chiefly supported by the ground; that in which it is mainly air-borne, but not uninfluenced by the contact of its wheels with the ground; and that in which it is wholly air borne and the pilot is adjusting his flight to the condition of steady climb and getting clear of the ground.

Again, when the pilot flies his aeroplane towards the aerodrome to make a landing he realises that, taking into account the angle of his glide, he must bring his aeroplane to a position close to the ground and in a condition of flight such that the translation from air to ground conditions may ensue immediately and in a kindly manner; and that, to reduce the chances of damage to a minimum and to use up the least space before coming to rest, the subsequent run, in which ground conditions prevail, will be as short as possible. In contra-distinction to getting off, the process of landing may be divided into *two phases*: that in which the aeroplane is air borne and in which the pilot is adjusting his flight so as to ensure favourable conditions for approximation to and contact with the ground; and that in which the aeroplane runs along the ground before coming to rest. The modern idea of landing excludes the phase in which the aeroplane is allowed to run along the ground with the tail up. The first phase, though somewhat complex, is difficult to sub-divide, for the onset of the influence of the ground is intimately bound up with the pilot's preliminary efforts to bring about conditions favourable to a good landing. Should these efforts have been ill-judged, the pilot's subsequent attempts at correction may serve rather to embarrass his landing than assist it; and what is more important, he is tempted to forget his rapidly receding powers of manœuvre, and under the influence of the increasingly urgent necessity of reaching favourable conditions prior to contact with the ground, he may ask more of the aeroplane than it can give.

It is only when the pilot has yielded to this temptation that the relative frailty of the structure of an aeroplane is brought home to him; he then realises how small a shock it need sustain to break, and how, if the maximum safe vertical drop on its wheels be small, a drop in which lateral or turning motion is included is many times smaller. Improvement of undercarriages in the properties of shock absorption and capacity to resist lateral loads may do much to mitigate errors in judgment, but it is well to emphasise how sure must be the pilot's judgment of the correct attitude of the aeroplane before contact with the ground

is contemplated, when the speed at which he must necessarily be travelling and the possible unevenness of the contour of the ground is taken account of. The average pilot has to fly for some time before his sense of the translation from air to ground conditions is sufficiently vivid to make him really reliable. When he is air borne and clear of the ground in a highly controllable aeroplane, a mere bank of 20° or so is hardly differentiated in his mind from rectilinear flight, so distantly related is it to the limiting kind of manœuvre which a pilot may not exceed without risk of breaking the aeroplane, and which is peculiarly confined to air handling. Not so when he is going to make contact with the ground. He is suddenly compelled to change his mental attitude towards the aeroplane; and this needs a distinct effort. Otherwise with a 20° bank on he may catch a wing-tip and turn the aeroplane on its back. A shock that the pilot hardly feels may be the prelude to a crash sufficient to "write off" the aeroplane. Many pilots, even those with considerable experience, have, after carrying out some violent "S" turns when manœuvring for position, suddenly realised that the ground is close and that the aeroplane is going to strike it; yet due to the persisting influence of air conditions have not made sufficiently drastic efforts to right the aeroplane, and so have crashed. The necessity of marshalling the aeroplane to a definite spot not only as regards position but as regards height, and, within small limits, of being at a definite speed at this spot, taken in conjunction with the sense of air freedom which the pilot has been enjoying, seems to constitute the psychological difficulty of landing well and safely.

3. Factors which influence "Getting Off" and "Landing."

The essential factor that influences the manœuvres of getting off and landing is the stalling speed of the aeroplane. The aeroplane must be somewhere near to the lowest speed at which flight can be maintained when its wheels leave the ground and when they again make contact with it. To this speed the pilot's mind sub-consciously makes reference. Therefore the flying qualities of the aeroplane at and near stalling speed influence the getting off and landing very powerfully. In flight these qualities can always be felt as distinct from those at high speeds, but they vary in different types of aeroplane due to loading, stability characteristics and relative size of the aeroplane, on which three factors, assuming normally designed control surfaces, the control seems chiefly to depend. And it is with the control, which is built on these foundations, that the pilot is vitally concerned. In getting off, the relative power of the engine will also influence the flying qualities near stalling. Unfortunately, as is well known, the flying qualities near stalling make a bigger demand on the control than those in any other attitude of flight; but owing to the low air-speed, this is just what the control surfaces cannot afford. Simultaneously with manœuvring for favourable conditions, the pilot must be ready to counteract large disturbing forces. Therefore according to his skill and the qualities of his aeroplane he is compelled to leave himself a certain margin of speed in excess of stalling.

At stalling two unpleasant characteristics assert themselves; a large couple comes into play tending to put the nose down, and the aeroplane tends to become laterally highly unstable in straight flight; in other words the aeroplane at the full ebb of the pilot's controlling powers, does its utmost to bang its wheels or its wing tip on the ground. The pilot is naturally anxious to leave the ground as soon as he is air borne, because, even assuming there are no abnormal obstacles to surmount, he wishes to be at the maximum possible height over the edge of the aerodrome in case of engine trouble; if he allows the wheels to continue running over the ground at a speed greater than is absolutely necessary, the aeroplane is sure to be bumped about and the last phase of its get-off impaired: that is, when it reaches the edge of the aerodrome its height will have been reduced. At the same time the pilot dare not cut short prematurely

the second phase of getting off while his controls are feeble and the disturbing forces large.

The foregoing remarks may be summed up by saying that the pilot always wishes, both in getting off and landing, to reduce the period in which his wheels are in contact with the ground and running over it, provided that in doing so he does not render the air-borne conditions just after or prior to contact with the ground so unfavourable as to be dangerous.

PART II.—"GETTING OFF."

1. Factors which particularly influence "Getting Off."

The principal factors which influence the pilot's handling in the manœuvre of getting off may be summarised thus :—

(*a*) The absolute dimensions of the aeroplane.
(*b*) The loading.
(*c*) The power of the engine or engines relative to the area and the weight.
(*d*) The position and effect of the propeller slipstream or slipstreams.
(*e*) The stability characteristics, assuming reasonable balance; and the effects of lack of balance.
(*f*) The control surfaces and their effectiveness, especially at low speeds.

Less important factors may be considered as :—

(*g*) The height, relative position and character of the undercarriage.
(*h*) The angle of the aeroplane to the ground with the tail down, and the height of the wings above the ground.
(*i*) The pilot's view of the ground, the contour of the fairing in front of him, and his position with regard to the C.G. and to the wings.

(*a*) In general, aeroplanes may be classified in size under four heads. The scout type, which includes aeroplanes of anything up to 300 sq. ft. in area; the larger single-engined two or three passenger type up to 800 sq. ft. in area; the twin-engined type up to 2,000 sq. ft. in area; and the large multi-engined aeroplane of 2,000 sq. ft. in area and upwards. The absolute dimensions give a fair measure of the liveliness of the aeroplane's motion in the air, and the magnitude of the control forces that the pilot may be called upon to exert. Small aeroplanes feel lively in the air, yet on the whole are the more readily controlled; large aeroplanes feel sluggish, but the control forces are greater and the response to the controls is slower. So for the inexperienced pilot, a medium sized aeroplane of 400 to 500 sq. ft. in area, which is reasonably handy without large control forces, presents the smallest difficulty in handling. With the smaller scouts the essence of the pilot's difficulty is that his mental response is frequently not commensurate with their inherent quickness; with twin and multi-engined aeroplanes that his physical response to opportunities of control is too feeble. And in getting an aeroplane off, as much if not more than at other times, these characteristics assert themselves. To appreciate rightly the quickness of the aeroplane's motion and the magnitude of its control forces, is the first requisite of safe manœuvre close to the ground near stalling point.

(*b*) For many reasons both in war and peace the tendency to build comparatively heavily loaded aeroplanes is strong. Up to, say, 10lbs. per sq. ft., the loading should not introduce serious difficulties. Assuming equal power, the heavier the loading, the longer is the run to get off, and the greater the demand on the pilot's skill in handling. The stalling speed is increased, and the aeroplane has to be travelling faster over the ground before leaving it, so allowing a smaller margin for the correction of errors of judgment. When the more heavily loaded aeroplane has actually left the ground with a reasonable margin of speed, it undoubtedly feels steadier than the more lightly loaded one. But once the

loading rises to an unreasonable figure the control is seriously impaired; so that even under normal conditions with smooth ground and plenty of space the aeroplane becomes difficult to get off, and under severe conditions dangerous. If the loading is abnormally high, the large aeroplane is considerably worse to handle than the small one.

(*c*) The most notable, perhaps, of modern features in design is the greatly increased speed range of the aeroplane of to-day. This has in some measure been brought about by the increase in its aerodynamic efficiency, but more especially by the design of high power for weight aero engines. The influence of the possible speed range in getting off is of great importance. In the early aeroplanes which had barely enough power to maintain steady flight, when practically all the power the engine would give was used up in lifting the wheels clear of the ground, the acceleration was so gradual that the aeroplane ran over the ground for a long way bumping about in a degree of control that can best be described as questionable. Photographs of early aeroplanes getting off frequently show one wing dangerously dropped. Even when the aeroplane was off the ground, its height over the edge of the aerodrome was so small that the pilot was the whole time under the influence of the proximity of the ground. The saving condition of these aeroplanes was their extremely light loading. A heavily loaded under-powered aeroplane of medium size is worse; worse still is an under-powered heavily-loaded aeroplane of large size; which is what, in commercial aeroplanes, is most essentially to be avoided. The attainment in a flat calm of a definite height at a definite distance from rest with a good margin of speed and consequently of control should be rigidly insisted on, and this height and distance should be such that the pilot is quickly freed from the embarrassment of the ground; for safety, nothing ought to stand in the way of it.

Assuming that the engine were perfectly reliable and leaving out the question of economy, the relatively high-powered aeroplane, if not overloaded, is the safer in getting off. With the exception of intenser slipstream effects, the flying qualities near stalling seem to be improved; pilots sometimes describe such an aeroplane as "almost hanging on its propeller," in which saying there is some truth. With the under-powered aeroplane, the pilot is always tempted towards stalling in order to get off at all; and if partially stalled, he receives little assistance from his overburdened engine. Yet one thing to be remembered is this: if, in the high-powered aeroplane, the source of power does suddenly become extinct, the violence of the change of conditions corresponds with the power that is lost, and the pilot is left to contend with difficulties, not indeed so great as in the continual wrestling with an under-powered aeroplane when the engine is running, but greater than in the change of conditions if it fails.

(*d*) In most aeroplanes the pilot relies on the slipstream for a certain measure of longitudinal control during the first phase of getting off. That the pilot can do without, or very nearly do without its assistance is proved by the flying of some twin-engined aeroplanes. Most modern single-engined aeroplanes can be held tail down with engine full out at rest when the elevators are pulled up and the maximum negative incidence put on the adjustable tail; but there is certainly one that cannot. Nearly all twin-engined aeroplanes, on the other hand, would be pulled over on to their noses by the engines under such conditions; if the tail is not held down only one engine can be run up at a time. The position of the undercarriage relative to the C.G. and to the thrust line, the angle of the tail relative to the thrust line and wing chord, and the size of the tail plane and elevators must be allowed for, but the practice in modern aeroplanes is similar enough for the above generalisation to be made. It will readily be seen that if with throttle full open the tail can be held down at rest without artificial assistance, there will be no tendency for the aeroplane to tip over on to its nose in the first phase of getting off. On the other hand, if the tail cannot be held down, the pilot, before opening full out, has to be careful to allow the aeroplane to

gather a little speed, by which time the wheels will have started moving and the aerodynamic forces which enable him to exert longitudinal control will be coming into play. He will then have reached the second phase. In one or two twin-engined aeroplanes in particular, the pilot feels the tipping tendency in the first phase in a marked way.

In all single-engined aeroplanes, the slipstream, besides acting on the tail-plane and elevators, acts on the fin and rudder. In twin-engined aeroplanes also the fins and rudders are seldom uninfluenced. In getting off the rudder has frequently to be moved through its maximum angle, and its value as an organ of control is impressed on the pilot by the extent of its deterioration at low speeds. Although during the second phase the rudder control is gaining in effectiveness, not only is it necessary to cope with general disturbances, but is required to counteract a disturbing force which seems to attain its zenith during the second and the early part of the third phase of getting off; namely the effect of the rotating slipstream on the fin. If the propeller rotates anti-clockwise looked at from in front, there is a lateral force on the fin tending to turn the aeroplane to port; if the propeller rotates clockwise, the aeroplane tends to be turned to starboard. A similar turning tendency is also evident in twin-engined aeroplanes with propellers of the same sense of rotation. The onset of this disturbing force tends to be if anything more rapid than the corresponding increase in power of the rudder. To cope with this force the rudder has often to be used to its full extent, and is therefore of little use for counteracting the temporary and evanescent disturbances that co-exist with it. The above contentions are based on the assumption that the turning tendency is severe; at least they show that when an aeroplane is being designed, no effort should be spared to reduce the turning tendency as much as possible.

(*e*) I have said that in getting off, an appreciation of the flying qualities near stalling is of the greatest importance to the pilot. Nothing affects these qualities more than the character of the aeroplane's longitudinal and lateral stability.

In considering the stability of the aeroplane some sort of balance has to be assumed. Laterally the aeroplane is trimmed so that it is in balance with its wings parallel to the ground, although almost inevitably it will be out of trim when getting off due to the turning tendency caused by the slipstream on the fin. Longitudinally, the average pilot may be assumed to try to arrange the balance before starting so that the aeroplane will trim at its normal climbing speed. In the longitudinally stable aeroplane, as stalling speed is approached, there will be a couple tending to put the nose down; and the more stable the aeroplane is, the larger it will become. In the longitudinally unstable aeroplane which is in trim at some normal climbing speed, the tendency is for the aeroplane to put its nose up as stalling speed is approached; and, though of course it does appear ultimately, for the nose-diving couple to be longer delayed; general flying experience seems to indicate that the aeroplane can be partially stalled without its appearance, and that when it does appear it comes into play very violently and without warning. The stable aeroplane gives the pilot plenty of warning that it is going to put its nose down when near stalling; the unstable one is amenable to a stalling moment produced by the elevators; it seems to hang for a considerable period, until it suddenly dives. The delay in the automatic dropping of the nose allows time for lateral instability to develop in a more aggravated form, and the subsequent dive is frequently the first phase of a spin.

You may sometimes hear a pilot say, "I like to trim my aeroplane nose heavy for getting off," or another say, "I like to trim my aeroplane tail heavy for getting off," the idea presumably being that they would adjust the tail during the third phase of getting off so that the aeroplane would be in balance near its normal climbing speed. At first sight this discrepancy of opinion would seem to be without logical foundation, but there may be a reason for it. May it not be the pilot's instinctive provision for the behaviour of the aeroplane due to its

stability characteristics? The stable aeroplane is always trying to put its nose down near stalling, so the pilot wishes to make the aeroplane tail heavy getting off. The unstable aeroplane at its lower speeds tends to stall itself, and the pilot tries to arrange its unstable trimming speed so that throughout the major part of the speed range it feels nose heavy. He is thus subject to the smallest control forces.

(*f*) The paragraph dealing with slipstream effects was inevitably concerned with the control of the aeroplane. During the first phase of getting off, the pilot has to rely mainly on the action of the slipstream on the elevators, fin and rudder; or has to be extremely careful if he uses them unassisted by the slipstream. During the second phase he uses his control surfaces to maintain the aeroplane in the most suitable attitude to gather speed, in order to give them effectiveness; his skill in handling is here tested, as he may in addition have to encounter disturbing forces exterior to the forces normally encountered. During the third phase he handles the aeroplane so as to maintain it at or near its best climbing speed. This speed is frequently just so much greater than the lowest speed at which the aeroplane can fly as to give him a reasonable margin of control. If the air is very disturbed he may by selecting a slightly higher speed increase this margin, which should not however seriously affect his rate of climb; and as a disturbed state of the air is usually associated with a wind of some sort, his height over the edge of the aerodrome will not thereby be decreased. It is a definitely dangerous practice systematically to underestimate the margin of control referred to, as the pilot can never quite foresee the disturbing forces he may have to deal with.

Unless it is imperative that acceleration should be as rapid as possible, the pilot does not open his throttle or throttles with a rush, but usually occupies two or three seconds over it. This serves two purposes; firstly it lessens the risk of choking the engine, and secondly it gives the wheels a chance of moving before the engine is exerting its maximum force tending to pull over the nose. Especially is this necessary where the elevator is only affected by the slipstream to a small extent. Once the aeroplane is fairly moving and the air forces have begun to act on the tail, the pilot, by lifting up the tail skid so as to make acceleration as rapid as possible, enters on the second phase. Due to the low speed, he sometimes has to push the control stick full forward at this time. The aeroplane will then probably bounce owing to the inequalities of the ground. The most awkward time for a bounce to occur is at the commencement of the second phase, when the elevator is down fully to lift the tail, and there is no control left to put down the nose if the aeroplane is bounced up. But speed is gathered quickly, and further bouncing is less serious; in fact the entry on the third phase is far more frequently the result of a bounce than of the pilot's volition. After this point, the pilot should not be worried by his elevator control if the engine runs well.

On the whole, the difficulties of lateral control, *i.e.*, rudder and ailerons, are more serious at low speeds than those of longitudinal control, for lateral control is achieved by a delicate co-ordination of two organs, not by a direct use of one. A bounce at the beginning of the second phase is not infrequently accompanied by the dropping of a wing, the results of which, if the aeroplane is not head to wind, may be serious. The yawing moment due to the ailerons has also to be reckoned with, for which the pilot has to be on the watch until he is well into the third phase.

In single-seaters and smaller two-seaters that have been fitted with balanced rudders and relatively small fins, a feature has been evident that must be clearly distinguished from the turning tendency due to the slipstream. There have been cases where although at all speeds in flight down to stalling speed the rudder has felt normal and not overbalanced, the aeroplane has swung violently and indiscriminately from side to side when getting off, and to maintain a straight course energetic paddling with the rudder has been necessary. This feature has been

termed "woffling." No bite is felt on the rudder, and the behaviour can be compared to the feel of an abnormally small rudder actually in flight. "Woffling" has however occurred in aeroplanes with quite large, and apparently under other conditions not overbalanced, rudders. The rudder does not take charge of the pilot; the aeroplane simply swings; and in order to correct the swing, the pilot has, as it were, to anticipate the motion and use his rudder to the full lock. Watched from behind, the swinging of the aeroplane seems just out of phase with the rudder movements. An increase of fin area seems enough to damp out this tendency to "woffle."

(*g*) The general type of undercarriage to which pilots are accustomed is the plain "V" type, the shock absorbing properties of which are derived from elastic. There have been certain undercarriages of the "Oleo" type, and a few in which wheels have been employed in tandem.

One of the principal features with which the pilot appears to be concerned is the height of the undercarriage, which is mainly responsible for the angle of the aeroplane to the ground. No matter how safe is the aeroplane to handle in flight, it must be safe to handle in the first and second phases of getting off. Experience shows that the higher the undercarriage—with the consequent raising of the C.G. and thrust line—the more difficult is the aeroplane to handle. If the aeroplane tips over on to its nose the impact is worse, and it is more likely to fling itself right over on to its back. Auxiliary forward wheels, if capable of sustaining the whole weight of the aeroplane, may of course do much to mitigate this; but the fact remains that the difficulties of getting off previously enumerated are aggravated by a high undercarriage. The aeroplane as a structure is simply top heavy; and with a high undercarriage this is unpleasantly impressed on the pilot.

When getting off on an aeroplane with a high undercarriage the tail may be lifted a certain amount and the aeroplane may feel quite normal; if, however, before the second phase is well advanced the tail is lifted more than this, it tends to come up very easily and the power of the elevator to maintain the aeroplane at a reasonable attitude feels unpleasantly limited. If the elevators are being pulled back during the second phase to correct perhaps a slight error of judgment in allowing the tail to come up too far, the pilot feels that he has not enough control left to raise the wheels clear of the ground when the suitable time arrives. The effects of bouncing under these conditions are also aggravated.

During the second phase the pilot is partly under the influence of air forces, and partly under that of the ground. He feels the bite of the wheels on the ground, and from this he estimates to a large extent the time to begin the third phase. The ordinary elastic spring undercarriages, while acting as fairly efficient shock absorbers, give a reflection of what is happening as the wheels run over the ground, which the pilot feels. The "Oleo" types, with more efficient shock absorbing properties, scarcely give the pilot any ground feel. In getting off, this is in some ways a disadvantage, though in the larger more sluggish aeroplanes that do not drop a wing suddenly, the effect on the pilot is admittedly less serious. The question of how much various pilots rely on the ground feel when getting off is however a difficult one to answer.

(*h*) It has been advanced that a low undercarriage makes it easier for the pilot in getting off. Unfortunately the chief means of arranging the wings at a large angle to the ground is the high undercarriage. Most aeroplanes, with the exception of those with abnormally low undercarriages, have their wings somewhere near the critical angle when sitting on the ground; in one or two the angle may be slightly greater, in the neighbourhood of 17°. It does not appear that a large angle on the ground assists the pilot to get off, as he frequently raises his tail during the second phase so that the centre line of the aeroplane is nearly parallel with the ground. It is when landing that the large angle to the ground is of assistance.

When, due to a low undercarriage, the lower planes are close to the ground, a tendency for a nose-diving couple to appear while getting off has been noticed. This nose-diving couple may be due to a cushioning effect. If the aeroplane is trimmed so as to be in balance near its normal climbing speed, during the first and second phases of getting off it feels nose heavy, and tends to keep its wheels on the ground too long. In other words the pilot has to pull it off the ground to rise into the air. On the other hand if the aeroplane is trimmed so as to be comfortable getting off, then it will feel tail heavy in flight.

Apart from this, the low position of the wings seems to make getting off more pleasant, and, if only to a small extent, to damp bouncing.

(*i*) The position of the pilot in the aeroplane and the contour of the fairing round and in front of his cockpit influence his handling in a marked way. A subconscious view of the wings stimulates his sense of lateral balance; while his sense of longitudinal balance is normally derived from some feature of the aeroplane such as a top longeron of the fuselage. He may be seated in such a position as to be denied one or both of these; and although in practice he soon accustoms himself to do without them, when available he always makes use of them. If, after flying an aeroplane with a more or less horizontal fairing in front of him, a pilot gets into one with the fairing sloping steeply down to the engine cowling or the nose, he certainly feels lost at first, and cannot gauge accurately the attitude in which he is getting off.

There are few pilots who, for pure controlling power, would not prefer to be situated close to the C.G. The pilot then feels that physically as well as mentally he is the hub of the machine which he controls. Curiously enough, it is more doubtful whether for getting off this is the case. During the first and second phases the feel of the controls is of less use than at other times, and the instruments are of practically no use; if the pilot is at a little distance from the C.G. the consequent accelerations on his body are an additional guide as to his attitude, which he can well dispense with, and of which during ordinary flight he finds it more pleasant to be free.

2. General Notes on "Getting Off."

During the manœuvre of getting off, the influences discussed above are as a rule only felt subconsciously; the pilot is busy watching the ground, to which ultimately he refers all his actions. Though it is true that in night flying the pilot's sense of the ground is somewhat diffused, it is rare for him to take up an aeroplane at night on which he is not experienced by day.

When getting off, the pilot is really concerned with three things: his attitude, the horizontal component of his velocity relative to the ground, which he feels roughly as his air-speed, and the vertical component, which he feels as the rate he is leaving the ground. His sensory impressions are the chief clue to these three things; he refers his attitude to the plane of the ground and its perspective towards the horizon, the horizontal component to the ground moving past, the vertical component to the ground as it appears to drop away. During the third phase the feel of the controls, the feel of his seat, and the air-speed indicator are of some assistance. As the pilot accelerates in getting off, there is some mental lag in the progressive accommodation to new conditions, and he is liable to over-estimate his speed, that is, he is at any moment travelling more slowly than he thinks; it will be seen that in landing the reverse is the case; he is therefore more liable to stall when getting off.

In Part I., para. (2), I divided the process of getting off into three phases. The most favourable attitude for the aeroplane during the first and second phases should be that of least resistance; the air drag is increasing, and as the wings lift more, the friction of the wheels on the ground is decreasing. Whether

pilots do achieve the most favourable attitude by feel is an open question; at least they tend to keep the tail down on sticky ground when the ground friction is high. Pilots vary in their attitude during the first and second phases between keeping the tail skid nearly touching the ground and lifting it to such a height as will bring the fuselage parallel with the ground. Considering the angle that the wings are usually set to the fuselage, the latter attitude is never exceeded. On hard and uneven ground many pilots prefer to get off with the tail well down, as the aeroplane feels pleasanter when it is bumped about. This may be accounted for as follows. If the aeroplane bounces on rough ground with the tail well up, the tendency when the wheels strike the ground is for the aeroplane to nose over, and the angle of incidence to be decreased, thus decreasing the total lift just at a time when the pilot wants it increased. If, on the other hand, the tail is down, a similar bump will increase the incidence and consequently the lift, which certainly makes the aeroplane oscillate less violently. Of course, there is always a risk of this being overdone and lateral trouble developing, but the unpleasantness does not seem so great as that in bouncing with the tail too much up. Again, if the pilot gets bumped up to a large angle of incidence, he may not have enough control to put the nose down gently; instead of this, the nose-diving couple comes into play and the nose drops too violently, the wheels again strike the ground, and an increasing kind of oscillation is set up. The pilot must exercise his discretion both ways, and good style is the result of a happy compromise

The co-ordination of the rudder and ailerons has been referred to as worth the pilot's close study. The sort of difficulty which frequently arises is as follows. The pilot is in the second phase, and due either to an air disturbance or a bump in the ground, one wing is thrown up and the other is dropped. The pilot tries to pull up the wing by using his aileron, in which he may perhaps be successful. At the same time the aeroplane tends to yaw due to the effect of the ailerons at low speeds. This yaw he has to correct with his rudder; but if his rudder control is all but used up in counteracting the rapidly developing turning tendency (referred to in Part II., para (1) (*d*)) and the aeroplane is caused to yaw the same way as it is tending to be turned by the slipstream, the rudder may be inadequate to deal with the two effects added together.

It sometimes happens in flying that the pilot comes to the limit of his controlling powers before he has achieved what he wants; the only thing he can then do is to allow the aeroplane its own will and gently convert its motion into another manœuvre, which is the next best to that he desires to achieve; it is absolutely no use trying to use the controls in the vain hope of achieving the impossible, for in doing so serious elements of danger at once appear. Two examples of this can be given.

Take the case referred to in getting off. One wing has dropped. The pilot dare not attempt to raise it due to the rudder being inadequate to cope with the yawing moment produced by the ailerons added to the turning tendency. He simply has to allow the wing to remain down, very near the ground, and get off on one wheel, converting the motion, if he can accelerate the aeroplane sufficiently to lift the wheel off the ground, into a gentle climbing turn. The dropped wing will then give the correct bank for the turn. He will now in a natural and flowing manner have converted a straight get-off into a get-off with a gentle climbing turn, although he had, as it were, to change his mind in the middle of the second phase.

Again, suppose the pilot has got off with a steep climbing turn in order to avoid some obstacle. He has to watch his flying qualities carefully because due to the turn he will be much nearer stalling point. Then, owing to a slight error of judgment, he finds the aeroplane partially stalled at about 200 feet from the ground. The controls begin to fail him. What is his only method of recovery?

He must lose some of his precious height to regain a margin of speed and control, and he must lose it in the most economical way. He must let the aeroplane fall into a turn in continuation of the climbing turn, swinging round again towards his starting point, gently easing the nose down with as little control movement as possible. Were he to move any of the controls violently in this critical state he would stall, and the nose-diving couple would crash him nose on into the ground. The most frequent mistake is to try and straighten off the turn by moving the rudder violently against it and pushing the stick forward in an attempt to put the nose down. The pilot thinks that if he could get straight he would regain control. No idea is more fallacious, and as soon as he attempts to move the rudder across he stalls with a violent sideslip, and gets completely out of control. Aeroplanes which exhibit weather-cock instability more especially have to be handled with care in climbing turns off the ground. If the pilot is trying to avoid obstacles, or manœuvring for a good position as early as possible should his engine fail, a climbing turn falls into the category of forced manœuvres.

The effect of wind has not hitherto been considered. If the pilot is not restricted in any other way, of course he gets off up wind. If, however, he has to surmount a serious obstacle in getting off up wind, and there is a clear run down wind, he may select to risk a less pleasant get-off down wind for the sake of the clear run. It requires much more skill to get off across wind than up or down wind, due both to the difficulties of the aileron and rudder control and the incapacity of the under-carriage to stand up to lateral loads. Again, if there is a breeze blowing at 100 feet from the ground, the wind gradient in the neighbourhood of the ground seems usually quite steep, and luckily for the pilot the air within three or four feet of the ground is seldom disturbed. Especially does this appear to be so at night. If the pilot gets off up wind, the wind gradient helps him in the form of an additional insurance against stalling, because he gathers speed more quickly. Getting off down wind, it acts just as surely against him; therefore no pilot would think of getting off down more than a comparatively gentle wind, except on a relatively high-powered aeroplane.

Getting off across wind is a different matter. Again, it is only attempted with relatively high-powered or manœuvrable aeroplanes. The great thing is to curtail the first and second phases in order even at the risk of stalling to get the aeroplane clear of the ground as soon as possible, and then to drop the wing that is towards the wind, sideslipping into it, to keep a straight course over the ground. In fact, if it is practicable, the wing should be dropped during the second phase, and the get-off effected on one wheel; for if the risk of being blown right over is to be eliminated, the wind must not be allowed to get under one wing. When getting off across wind, lightly-loaded aeroplanes are the more difficult to handle during the second phase, due to the more violent effect of the wind; heavily-loaded aeroplanes during the third phase, due to the higher stalling point, and the temptation of the pilot to get them off at too low a speed.

3. "Getting Off" as a Forced Manœuvre.

This paragraph will deal with getting off under unnatural conditions. Suppose the pilot has to fly an aeroplane out of a small field surrounded equally by obstacles, he would naturally wish for a strong wind against which to get off; suppose again that the field is restricted on three sides and the wind is blowing from one of the sides adjacent to the open side, the obstacles on this side being too high for him to surmount, he has the choice of getting off either with a climbing turn, or if there is not enough room for this, towards the open side across wind. It should be noted that more frequently than the actual space of ground available before the wheels lift, it is the obstacles which surround it that worry the pilot, at least in English country.

Take the first case, where the pilot is compelled to surmount the obstacle. Unless it takes the form of steadily rising ground, the pilot would, during the third phase, hold the aeroplane down near the ground gathering as much speed as possible, and then, using up all the energy available to lift him clear, "zoom" as he approached the obstacle and allow himself to sink on the farther side. He could thus surmount a higher obstacle than if the third phase took the form of a steady climb. If, however, the condition at the farther side of the obstacle is to be that of steady climb, R. McKinnon Wood shows, in a theoretical analysis, that nothing is gained by the "zoom." Nevertheless, not only does a "zoom" enable the pilot to surmount a higher obstacle if he allows himself to sink on the farther side, but it means that during the period of the third phase, in which he is holding the aeroplane near to the ground, he will due to his speed have a greater margin of control in preparation for the final effort. If the pilot tries to surmount the obstacle by a steady climb, he is liable to attempt the climb at a very low air-speed, probably lower than his best climbing speed, under the impression that he is climbing faster due to the steep attitude of his aeroplane. In a steady climb at a low air-speed his control will be difficult throughout a sustained period, while in the "zoom" the period during which his control is reduced to a minimum is very short. In the kind of get-off just considered, the pilot naturally makes full use of any head wind there may be.

The second case, where in order to avoid the obstacle the pilot has either to get off with a climbing turn up wind or else straight and across wind, is a different one. The pilot's handling during the climbing turn and when getting off across wind have already been dealt with. If the wind is strong, the climbing turn would probably be preferred; if gentle, the get-off across it. A certain amount can be done to assist the get-off by holding back the aeroplane on the ground by artificial means while the pilot opens the engine full out, and then letting it go; but the pilot must be very sure of his powers of holding down the tail in the slipstream before he can practise this with safety (ref. Part II., para. (1) (*d*)).

If the surface on which the pilot has to get off is wet and sticky, he has to allow very much more time to get clear. As was stated before, he can only try to keep his tail down as much as possible, and never to get off on sticky ground down wind.

The last thing to be considered under getting off is engine failure. This must occur when the pilot is still under the influence of the ground, and from such engine failure more crashes result than from any other one cause. If the engine fails during the first or second phases, the aeroplane can nearly always be brought to rest by the pilot without damage of any consequence. In the third phase his situation is one of peculiar difficulty. When getting off, the pilot should always attempt so to manœuvre his aeroplane that should engine failure occur at any moment during the third phase, he will be able to effect a landing on reasonably good ground. With some aerodromes this is difficult; with many fields it is impossible. Nevertheless, it is an aim which should never be lost sight of, and in pursuance of which the climbing turn is particularly helpful. If there is a good piece of ground outside the aerodrome in the up-wind direction, the pilot should not fly directly towards and over it, for if his engine fails it may be hidden from view beneath his wings; he should manœuvre so as to be just on one side of it, so that he always keeps it in view until the completion of the third phase.

If the engine fails near the ground, the trim of the aeroplane may be violently upset, both longitudinally and laterally, and the pilot is bound to lose some height before he regains mental equilibrium and brings the aeroplane to a safe gliding attitude. The chief cause of crashes seems to be the desire of the pilot to turn back down wind in an attempt to land in the aerodrome which

he has just left. It is surprising how long it appears to take after climbing steeply with full engine to gain a margin of speed gliding, and how much it appears necessary to depress the nose of the aeroplane. And this must be attributed to the proximity of the ground. The pilot is tempted to commence his turn back before he has gained sufficient gliding speed, and so commences a spin at a low altitude from which there is no recovery. If he has not enough height—300 feet is about a minimum—it is imperative that he should glide on and make some sort of a landing even in very bad ground. It is better to approach bad ground with the power to flatten out than good ground without it. Another feature of the turn down wind is the way in which the apparent rate of travel of the ground up and down wind deceives the pilot. As he turns down wind he thinks he is going faster than he really is, which as it occurs on a turn, puts him, unless he takes the greatest care, in danger of stalling. It is far better to trust to the air-speed indicator reading than to watch the ground under these conditions, and make sure that the margin of speed really exists; for in gliding the stall develops so quickly after the controls first begin to feel sloppy, and the imminent approach of the ground appears so rapid, that the pilot has little chance to correct his error. His best plan, just as in the case of the "zoom," is to dive and gain as much speed as he can before approaching the ground; and rather than commence the turn at a dangerously low speed, carry it out with what speed he can gain during the dive.

The question of engine failure in getting off naturally leads up to a consideration of landing, and engine failure at the beginning of the third phase, when the wheels have just left the ground, will be discussed under that head.

PART III.—LANDING.

1. Factors which particularly influence "Landing."

As the factors to be discussed are mainly those which influence the flying qualities near stalling speed, most of them are common to the manœuvres of "Landing" and "Getting Off." As was stated in Part I., para. 2, the period of landing will be divided into two phases; the moment of contact with the ground terminates the first and introduces the second.

The factors which particularly influence landing may be enumerated as follows :—

(*a*) The absolute dimensions of the aeroplane.
(*b*) The loading.
(*c*) The stability characteristics and the balance of the aeroplane.
(*d*) The control surfaces and their effectiveness, especially at low speeds.
(*e*) The effect of the slipstream.
(*f*) The height, relative position and character of the undercarriage.
(*g*) The angle of the aeroplane to the ground with the tail down, and the height of the wings above the ground.
(*h*) The pilot's view of and his height from the ground, and his position relative to the C.G. and to the wings.

(*a*) Taking the four sizes of aeroplane considered in Part II., para. 1 (*a*), it may generally be stated that the twin-engined type is more difficult to marshal to the landing position, though simpler to land when correctly in position; that the scout and smaller single-engined two-seaters are easier to manœuvre for position, but actually more difficult to land. The very large aeroplane is seldom manœuvred at all, just simply flown in, using one group of engines to prolong the glide. The three phases of getting off require a steady effort of judgment the whole time, while although the approach to land does require nice judgment,

the chief effort during landing is more especially concentrated round the few critical moments when the aeroplane is just about to touch the ground. During these moments the timing of the stalled condition must be in complete harmony with the aeroplane's height above the ground, for the slightest error spoils a good landing and involves a disproportionately bad one. Though a bad landing may be saved by the use of engine, it is nevertheless a potential crash.

The larger types of aeroplane are as a whole easier to land because they are more sluggish and extend the critical period just before contact, so that the pilot has at least the chance of correcting small errors. On the other hand, the smaller aeroplane is more handy during the approach; natural drift can be quickly eliminated, or artificial drift introduced to meet abnormal conditions. If a large aeroplane is drifting near the ground, its sluggishness inhibits the quick removal of the drift. If the smaller aeroplane becomes partially stalled, speed may be regained in time to flatten out. The response of the larger aeroplane under these conditions is so slow that it is actually necessary in order to flatten out to get up a considerably higher speed than would normally be required.

(*b*) Most pilots have noticed the difference in the stall of an aeroplane when it is flown light, and then loaded up heavily. When light, the engine may be switched off and the nose gradually pulled up until the aeroplane sinks gently and puts its nose down again. Load the aeroplane up, however, carry out the same stalling operations, and the aeroplane will answer the elevators until suddenly it drops the nose, usually in conjunction with one wing, and feels as if it wants to spin. Furthermore, the stall occurs at a higher speed. There is a double reason for precluding such slow safe flight; the stall occurs sooner, and the flying qualities associated with it are worse.

As in getting off, the large heavily-loaded aeroplane is worse to handle than the small one. With the small racing scout loaded to an abnormally high figure, the pilot takes his own risk about landing; but as long as landing is purely an effort of judgment, safety on the larger commercial aeroplanes must demand a low landing speed. The tendency is therefore to search for wings whose form may be varied in flight in order to increase the speed range of the heavily-loaded commercial aeroplane by giving an absolutely safe landing speed while retaining a reasonable top speed. Whether the speed range be increased by relatively high power with a fixed wing section and a high landing speed or by variable camber wings and a reduction of the landing speed, there is a definite effect produced on the pilot. If he flies an aeroplane with a big speed range and attempts to land at, say, a third of the speed at which he has been flying, he has, due to the lag of his senses in accommodating themselves to the new conditions, the feeling that he cannot reduce his speed to what appears to him a ridiculously low figure; he feels that he must be stalling, and consequently tends to come in to the aerodrome too fast. With a big speed range it is really difficult to make use of the very lowest speeds that may be safely possible. The pilot is always going faster than he thinks. This effect is particularly noticeable if high speed aeroplanes are watched coming in after a race. They nearly always, allowing for the high loading, tend to come in unreasonably fast because of the pilot's difficulty in adjusting himself. Motorists experience this when a ten-mile limit is approached after motoring fast on the open road.

(*c*) The longitudinally unstable aeroplane is more difficult during the earlier part of the first phase of landing, the stable aeroplane more difficult actually to land. Taking into account what was said about relative size, the large unstable aeroplane is to be avoided at all costs. When in the first phase the pilot is approaching to land the unstable aeroplane, he has to maintain it at the correct speed, and is more likely to be deceived into stalling, especially on a

turn; the stable aeroplane, if the tail adjustment admits, and it should admit, can be made to assume a natural gliding speed without trouble, to which it always tends to return.

It will be seen that an unstable aeroplane, although near stalling its instability tends to be reduced, really tends to land itself. The wheels and tail-skid will have probably made contact with the ground before the nose-diving couple is felt. If the unstable trimming speed is arranged to coincide with or slightly exceed the desired speed of glide, the pilot has only to release the control stick at the right moment and the aeroplane will naturally stall itself gently on to the ground; in any case, with very little effort the pilot can gently check or assist the motion to bring about a favourable conclusion.

If the aeroplane is stable and is set to trim at the desired speed of glide, the stalling moment of the elevators will be progressively opposed by the effect of longitudinal stability, until just before contact with the ground the nose-diving couple requires the full upward movement of the elevator to counteract it. The movement of the control stick to flatten out begins gently and ends in a comparatively violent pull right back that must be perfectly timed; if it is made a moment too soon, the control is all used up and the nose-diving couple bangs the wheels on the ground. The onset of the nose-diving couple may be in some measure postponed by arranging the trimming speed to be slower than the desired speed of glide, that is, making the aeroplane feel slightly tail-heavy gliding; but this always introduces the tendency to stall during the earlier part of the first phase.

Unlike longitudinal instability, lateral instability does nothing but increase the pilot's difficulties. Dihedral certainly postpones the dropping of one wing, and aeroplanes with no dihedral drop one wing very quickly and land hard on one wheel if not stalled directly on to the ground. But practically all aeroplanes show this tendency to some degree, which is just what the aeroplane, as a structure, will not stand. The drop that an aeroplane will stand up to on one wheel is insignificant compared to the drop on both wheels equally; and it is nearly always heavily-loaded aeroplanes that upset the pilot by suddenly dropping a wing.

(*d*) Professor B. M. Jones has said that a truer criterion of the landing difficulty than the stalling speed is the slowest safe speed of manœuvre near the ground, and suggests that although in general the margin of speed necessary with different types is at present of the same order, this margin could be materially reduced if the control near stalling could be improved. I think that it is on the confidence that the flying qualities near stalling give to the pilot that he bases his judgment of the lowest safe speed. In most aeroplanes the lateral trouble develops first; and if the aeroplane, though highly controllable longitudinally at low speeds, is vicious laterally, the extra longitudinal control will avail the pilot practically nothing. It is essential that if the flying qualities near stalling are to be improved the lateral and longitudinal be kept on a par; and in present-day aeroplanes the lateral element needs improving to bring it up to the longitudinal.

A feature that tends to mar the longitudinal control is a large difference of trim with engine on and off. Not only should the range of the adjustable tail be amply sufficient to cope with this, but the difference should be reduced as much as possible to make the necessity of a large tail range remote. The pilot does not want to be hampered in making full use of his primary organ of longitudinal control, the elevator, by compulsory attention to his secondary organ, the adjustable tail plane. Especially does this hold should he be compelled to make use of his engine suddenly to save a bad landing. He has no time or energy to concentrate on anything but the simplest control mechanism when he is in close approach to the ground.

During the war a form of air brake was fitted to a service aeroplane with the idea of increasing the gliding angle and pulling the aeroplane up on the ground. H. Glauert has pointed out in R. & M. 667 that the speed drops so rapidly in the run along the ground as to render such brakes of little use. The increase of gliding angle certainly does assist the pilot to get into a confined space over obstacles, but a distinct danger arises from the fact that the pilot is likely to bring his air brakes into action while coming in without realising what his change of gliding angle means. To glide in at the same speed he must keep his angle of incidence the same, and so must rotate the body of the aeroplane through the change in gliding angle. Because he suddenly glides steeper the idea is presented that he is going correspondingly faster, and on this assumption he may commence manœuvres which he would not otherwise attempt. It is always a question whether it is wise for the pilot to change the characteristics of his aeroplane when under the influence of the ground.

In getting off, with the point at which he leaves the ground as his starting point, the pilot has, within fairly wide limits, freedom as to his subsequent direction; his lateral control is mainly necessary for counteracting casual disturbances and only in a wide sense for voluntary manœuvre. In landing, on the other hand, his manœuvres are executed with the express purpose of arriving at a definite point; and, if he is unwilling to face judging a long straight glide or relying on his engine, they may be termed compulsory, almost involuntary, manœuvres. His lateral control is then more important still, for it has to be utilised to counteract disturbances simultaneously with the execution of low-speed manœuvres. Although the aileron control has not been found in practice to reverse, the yawing moment due to the ailerons is more noticeable even than in getting off, probably owing to the small slipstream effect on the rudder. Some pilots actually appear to utilise the yawing moment to assist manœuvres for losing height at the edge of the aerodrome, but unless the pilot is experienced, considerable risk is involved.

The rudder control suffers badly at low speeds, for if the rudder is made small enough to be reasonably light at high speeds, it is usually overpowered by the ailerons near stalling. This may be, and is, partly overcome by the use of balanced rudders, but the balancing itself, if carried out to any extent, introduces other difficulties.

Some aeroplanes, especially those without steerable tail-skids, show a tendency to spin round on the ground during the second phase, and the rudder is not sufficiently effective to prevent this spin. The pilot might give the rudder more power by a burst of engine and the subsequent slipstream effect; but he is often unwilling to increase the speed at which he is running along when on a turn. In any case it is unwise to check the turn too violently; the aeroplane should be allowed to go on turning until nearly all speed is lost before risking a burst of engine.

(*e*) It is not always sufficiently realised how different an aeroplane feels when the engine is throttled down for gliding and when it is completely switched off. The pilot relies more than he knows on this slipstream effect, small as it is, to assist his rudder. If his engine fails completely, and he has not tried flying the particular type of aeroplane with no engine at all, he frequently experiences a feeling of helplessness for a few moments until he has accommodated himself to the new conditions. The rudder control of many aeroplanes at low speeds without any slipstream is by no means satisfactory, neither are these difficulties imaginary.

When carrying out manœuvres for losing height at the edge of the aerodrome, the pilot finds an occasional burst of engine of the greatest use to assist his control. These bursts of engine are not always given, as is often supposed, to

prolong the glide. As has been stated before, the secret of manœuvring at low speeds is the co-ordination of the rudder and ailerons; lack of co-ordination means a loss of height, and more important, of direction, before the error can be corrected. The pilot is thus hindered in his attempt to arrive at the desired landing point. When the rudder and ailerons are not co-ordinated properly, the aeroplane, if on a turn, seems to stick, or its motion becomes jerky. A burst of engine, especially in a large aeroplane, will often relieve this condition at once by assisting the rudder.

(*f*) If the undercarriage is high, the pilot feels that his aeroplane as a structure is top heavy during the second phase of landing. If for a moment the value of a large angle of the wings to the ground is set aside, the pilot always feels safer if the vertical distance from the wheel axis to the C.G. and to the line of thrust is kept to a minimum, because the overturning tendency is thereby reduced. He further realises that if he does go over, the impact will be much less severe.

The necessity of ground feel, advocated for getting off, is of no importance in landing, probably because the conditions of the second phase of getting off are generally avoided. In landing, the aeroplane is either definitely air borne or running along with its tail-skid on the ground. In getting off it was noticed that an Oleo type of undercarriage tended to eliminate the ground feel which was of value to the pilot, whereas in landing this is of no moment, and excellent shock-absorbing properties are essential to preserve the structure from damage.

One of the worst features of the present-day undercarriage is its incapacity to stand up to lateral loads. The pilot has always to concentrate on eliminating drift prior to contact with the ground. This, due to the bad rudder control at low speeds, is often difficult to achieve. Consequently a large proportion of minor crashes are due to landing with drift and the subsequent collapse of the undercarriage.

In the simple "V" type of undercarriage, the wheel position, which even now is quite a delicate matter to determine, is of the greatest importance. It usually has to be settled by practical trial. If the wheels are too far back, the overturning moment may be more than the controlling moment of the elevators with the reduced slipstream, especially if the aeroplane bounces in landing. If the wheels are too far forward, the aeroplane is inclined to "bucket" and an oscillation is set up, which if not taken in hand by the pilot and damped at an early stage, may also result in the aeroplane turning over. If the aeroplane starts to "bucket" the tail-skid receives severe shocks. The only advantage of wheels placed far forward is that landing on soft ground is made easier. The advantage to the pilot of such a wheel position can be reproduced on commercial aeroplanes where the maximum reduction of weight and resistance is not so essential as in war aeroplanes, by wheels placed in tandem. If ground brakes are employed, and it seems likely that they will be necessary in future, tandem wheels are essential. H. Glauert points out in R. & M. 667 that if ground brakes are employed a reduction of the run is only effected by increasing the angle of the wings to the ground above the critical angle. If the increase of angle is within limits below the critical angle, the run is not sensibly shortened.

Especially on large aeroplanes a wide wheel track is of great advantage in steadying them if they are not landed with the wings level. One small scout at least has been successfully fitted with a wide track undercarriage. Although this aeroplane is inclined to oscillate sideways due to uneven ground, it lands well and safely, and has less tendency to spin round on the ground after landing. On single-engined aeroplanes built for war purposes, the undercarriage has usually been fitted to the fuselage unit, which has more or less settled the width of the track. For commercial aeroplanes a wide track should make them on the whole easier and safer to land.

The pilot can make a safer landing on soft ground by having his tyres fairly soft so as to widen the effective tread.

To sum up, it is suggested that the vertical distance from the wheel axis to the C.G. and thrust line should be kept to a minimum; that undercarriages should be made capable of absorbing side shocks to a much greater extent; that the desirability of good shock-absorbing properties is in no way lessened by a necessity for ground feel in landing; and that on commercial aeroplanes tandem wheels combined with the widest wheel track possible will make for safety and ease of landing.

(*g*) The low undercarriage, although it may reduce the angle of the wings to the ground, tends to bring them closer to it. H. Glauert in R. & M. 667 does not seem to attach much importance to the effect of a low wing position, at any rate, for reducing the run. It has been a matter of flying experience, however, that certain aeroplanes whose lower planes were close to the ground, within half a chord, were notably easy to land. The wings definitely felt as if they cushioned against the ground and the aeroplane did not appear to drop a wing so easily. This may have been in some part due to the fact that the proximity of the wing to the ground made it easier for the pilot to judge his height prior to contact; but the fact remains that it was a widely expressed opinion. The couple tending to put the nose down due to cushioning has not, as in getting off, been sensibly noticed by pilots. A large angle of the wings to the ground undoubtedly does reduce the run of the aeroplane, but in landing the pilot feels it more difficult to get his tail down, neither is his position so comfortable, as the nose tends to rise up in front of him and block the view ahead.

(*h*) It is naturally essential for the pilot to have a good view during both phases of landing—as he is gliding down in the approach, as he makes contact, and during the subsequent run. As he approaches, he must be able to see if the landing space ahead is clear, or otherwise he is timid and uncertain in his preliminary manœuvres. When he is about to make contact with the ground, it is unwise to try and gauge the height of the aeroplane from the ground by looking down steeply over the side, and worse still to look back at portions of the aeroplane such as the wheels, even should they be visible. Among other things, his sense of lateral balance is certain to be upset. He should look at the ground about fifty yards ahead, at which distance it does not appear to be moving very rapidly, relate its appearance to the general perspective of objects towards the horizon, and thus judge his attitude relative to the ground. If he looks down at the ground rushing past near to him, its apparently rapid movement tends to unbalance his judgment.

In a few aeroplanes, while the view downwards is good, the view forwards is restricted too much by the spar of the top plane being brought too near the level of the eyes—with the object of allowing the pilot to look over it. For landing, he is compelled to look downwards rather than forwards and his judgment is interfered with.

Although experienced night-flying pilots can land at night with little or no illumination, the average pilot needs a set of flares, unless he lands down the beam of a strong searchlight. He has to concentrate not on where he supposes the ground to be, but on the perspective of the flares; when they become nearly superimposed he flattens out.

Within limits the pilot accommodates himself easily to landing large aeroplanes in which his seat is a large vertical distance from the ground. Experience seems to indicate that the lower the pilot is, the easier it is for him to land; but it has not proved how high the pilot can be seated without encountering real difficulty.

Provided the pilot is not at an abnormal distance from the C.G., for landing the position of his seat does not appear to affect him much. If he sits behind the planes, the consciousness of them assists his judgment; on the other hand, his view is so much better if he sits in front that by losing the first advantage he gains the second. It is, however, always helpful to have some sort of fairing in front of him which will assist his idea of the attitude of the aeroplane.

2. General Notes on Landing.

In the earlier days of flying the modern "tail down" landing was seldom, if ever, practised. The aeroplane was glided down, and in the case of such scouts as then existed, at an excessive speed for fear of stalling; after which the pilot attempted to run along the ground with the tail up, allowing it gradually to sink down as the aeroplane slowed up. Such landings were nearly always associated with violent bounces, due to uneven ground, and corresponding risk of damage. War conditions forced the pilot to change his attitude. If aeroplanes were to be landed on soft or rough ground in confined spaces, the problem of landing would have to be more finely appreciated. And it was. Consequently the practice was made of getting the tail right down before making contact with the ground, and was not after all found so risky as had been supposed. The risk of dropping a wing, as time went on, was further diminished by better design.

Supposing for the moment that the pilot makes a straight approach to the landing space, he may have some latitude both in the line of his flight and in a lateral direction as to where he may safely make contact so that his subsequent run may be all on good ground. But when, travelling at a minimum of 60 m.p.h., he views the landing space from the air, it looks surprisingly small and gives him an unpleasant sensation of constraint. If the latitude as to where he may touch the ground in the line of his flight is 300 yards, the maximum period he will have in which to make up his mind is roughly 10 seconds, after which time he will have overshot his mark; or alternatively, assuming a gliding angle of 1 in 6, he must judge his height over an obstacle within 150ft. The flatter the gliding angle of his aeroplane, the more will this margin contract. As a matter of fact, the pilot very seldom attempts to judge a straight up-wind glide; he approaches the landing space with a margin of height, and loses it by a series of manœuvres which will be discussed later.

Associated with the tail up landing practised in earlier days was a kind of rapid flattening out. The aeroplane was glided down and, until it was within a few feet of the ground, flattening out was postponed, and was correspondingly violent. The pilot then allowed the wheels to touch and so ran along until the aeroplane came to rest. This kind of flattening out, however, can be made in conjunction with a tail down landing, which means that the pilot keeps the aeroplane near to the ground without making contact until it stalls. The greater the speed at the time of flattening out, the longer the period before contact with the ground. This holding the aeroplane near to the ground is a severe tax on the pilot's mental concentration, as the flying qualities change with the loss of speed and the controls require the most delicate handling. If the pilot becomes fatigued, he lets the aeroplane either touch the ground too soon or curve up into the air again and stall too high.

Most pilots therefore try to diminish the period close to the ground by commencing to flatten out at from 20ft. to 30ft. up, thus approaching the ground more gradually. If the pilot could foretell the precise moment at which the aeroplane was in a suitable condition for contact with the ground, he need never consciously hold the aeroplane near to it; in practice he dare not risk such an accurate forecast, and always tries to allow at least a small period to elapse while he holds the aeroplane very close to the ground, awaiting the final condition of stalling. Pilots often refer to this as "flying the aeroplane right out." In forced landings the pilot may elect to bring the aeroplane in so slow and right on

the edge of his controlling powers, that the period referred to becomes sensibly zero. But should his judgment be in the slightest degree out, a crash is inevitable, especially as he may have no engine to accelerate him at the last moment.

The normal gradual flattening out may actually be associated with a manœuvre such as turning or side-slipping, by which it is apparently masked; but the pilot must so arrange the manœuvre that a form of flattening out is really inherent in it.

In landing, as in getting off, the pilot is concerned with three things: his attitude, the horizontal component of his velocity relative to the ground, and the vertical component; the relative magnitude of which two components determines his gliding angle. The pilot arrives at a point from 20ft. to 30ft. above the ground, gliding at some speed at which he has a reasonable margin of control. From this point his path becomes curved; at any moment the lift of the aeroplane is just greater than the weight, and immediately prior to contact with the ground, the vertical component of his velocity should be reduced for a perfect landing nearly to zero. Now, neglecting the effect of the propeller, there are two factors which influence the control movement necessary to produce the required path. Firstly, the stalling moment necessary to be produced by the elevators; and secondly, the negative acceleration at any moment during the time that the attitude of the aeroplane is changing; for as the speed drops, the resistance at any moment changes. At some moment prior to stalling, the aeroplane may pass through an attitude of minimum resistance. This attitude, on the other hand, may be that corresponding to the speed at which the aeroplane is gliding when the flattening out commences; in most cases it is probably in the neighbourhood of this speed.

Suppose that the aeroplane is initially gliding at its best gliding angle, that is, with minimum resistance; and suppose the speed which corresponds to this is 60 m.p.h. The subsequent curvature of its path will be associated with the alteration of its attitude and its corresponding loss of speed, the whole being made to culminate in the desired conditions just prior to contact with the ground. The pilot, by the use of his elevators, has to ensure that speed is gradually and steadily diminished throughout the curved path, and this dictates his attitude. Immediately the pilot commences to flatten out the aeroplane, which is assumed to be gliding at its best angle at 60 m.p.h., he will drop the speed. But at this lower speed the resistance will increase, and progressively so towards stalling. So to produce the curvature of path that he desires, the speed must decrease more and more rapidly as the ground is approached, and the attitude of the aeroplane must be altered to correspond, or the pilot will fly into the ground. The pilot does allow for it by a progressively more decided use of the elevators. As it happens, he has to use his elevators more decidedly as the speed drops, for two reasons: firstly, for the one mentioned, and secondly, because as the speed drops the control becomes increasingly less effective. It is, of course, by his sense of the rate of approach of the ground that the pilot allows for all these somewhat complex effects. It is emphasised here that the progression is all towards using the control more decidedly as the stall is approached.

But now suppose that the pilot, possibly for fear of stalling the aeroplane because he is being bumped about on a rough day, glides the same aeroplane in at 75 m.p.h. The resistance at 75 m.p.h. is greater than at 60 m.p.h.; so if his path is straight, the vertical component of his velocity is greater. When he commences to curve his path, the approach towards the attitude of minimum resistance requires a progressively less vigorous control movement to flatten the aeroplane out relatively to the ground; but there will come a critical time when the attitude of minimum resistance is passed and it becomes steadily greater. It is here that the pilot is likely to be deceived. The fall of resistance and the sensitiveness of the control at the higher speed, at first seemed to stave off the approach of the ground with a negligible effort on his part. After the critical

point, he suddenly finds himself into the ground with a violent bounce, because he has not allowed for the more rapid decrease of speed. It is suggested that the above may be an explanation of why the pilot so often tends to fly into the ground if he glides in fast, that is, at a speed greater than that which corresponds to the attitude of minimum resistance or best gliding angle. On the other hand, the effects described above are probably masked in many cases by the stability characteristics of the aeroplane.

Whether the pilot curves his path gradually over a long period, or suddenly over a short one, the above remarks apply in the main. The advantage of not having to hold the aeroplane close to the ground for a protracted period, while it "flies itself out," is seen to be that the consequence of a slight error in the allowance for the change of the vertical component of the aeroplane's velocity is not so likely to be followed by a violent bounce. More times than not, a pilot involuntarily performs the high-speed rapid flattening out type of landing through an ungovernable shrinking from a reduction of speed, especially when the air is disturbed. In reality the type in which he gradually flattens out is his ideal of good style. As in all flying, violent control movements, unless dictated by imperative conditions, are the result of subconscious timidity or uncertainty of the pilot.

H. Glauert states in R. & M. 667 that a reversible airscrew would be of the greatest assistance in reducing the space required for landing. As long as the success of a landing is so intimately bound up with an exquisite kind of judgment, it would be difficult for the pilot to operate any kind of auxiliary control once he came under the influence of the ground, however useful it might prove in reducing the landing space. H. Glauert further points out that a reversible airscrew would not be available in the case of a forced landing without engine. It might be added that the pilot would be precluded from using his engine to increase the curvature of his path, should he need it at a critical moment.

If there is a wind, the pilot always lands against it. Just as the wind gradient near the ground assisted him in getting off, it disturbs him in landing. If the pilot lands against a strong head wind, he often, as he approaches the ground, feels himself unaccountably dropping. This must in many cases mean that he tends to lose speed without realising it, due to the drop in the velocity of the wind near ground level. With the exception of this effect, there is nothing to fear from landing into a strong wind, as the actual speed of the wheels relative to the ground when contact is made is very low, and the subsequent run correspondingly short. It is a curious fact that when landing into a strong wind pilots so frequently tend to make contact with the ground with the tail up. This must be because they feel themselves travelling so much more slowly relatively to the ground that they are led into believing that stalling speed has been reached and that the aeroplane is ready for contact with the ground.

Although it has been pointed out that the pilot nearly always loses height near the edge of the aerodrome by manœuvring as a matter of course, these manœuvres will be considered in the paragraph dealing with forced landings, in which they are the decisive factor. Landing across wind, although sometimes deliberately practised, will be dealt with in a similar way. Landing down wind is not considered, as a modern aeroplane cannot be landed down a wind of any strength without the most severe risk of a crash. Furthermore, there seem to be no particular methods by which the pilot can diminish this risk.

3. "Landing" as a Forced Manœuvre.

Engine failure in the air means a forced landing, which, as has been stated before, is usually taken as the ultimate test of the pilot's skill and judgment. Sometimes the pilot is able to avail himself of a small amount of engine, which, though it will not enable him to climb up and try a second landing should he

misjudge at the first attempt, serves to prolong his glide. The breakage of any essential part of the engine usually means switching it off altogether. If such a breakage occurs on a twin-engined aeroplane, unless the pilot can stop the propeller of the damaged engine, he will probably find it necessary to glide down as quickly as possible owing to the liability of very severe vibration being set up and the consequent menace to the aeroplane structure.

As in getting off, it is usually the obstacles which surround possible landing spaces that constitute the difficulty; so, especially if the gliding angle is flat, the pilot must, if for no other reason, have recourse to manœuvres to bring the aeroplane to the ground as soon after the obstacles as possible.

Engine failure may occur either at the beginning of the third phase of getting off, when the wheels have just left the ground, or towards the end of the third phase; or when the pilot is well up and free from the influence of the ground. In the first case the pilot is compelled to effect a landing immediately in his projected line of flight, trusting that he will not overrun the limits of good ground before coming to rest. Landing under these circumstances is difficult to execute without very severe bouncing and consequent risk of damage. The pilot finds himself somewhere near his best climbing speed, close to the ground, with the slipstream effects suddenly eliminated. Depending on how close he is to the ground, there are two courses open to him. If he is only 3ft. to 6ft. up, he may, without moving his longitudinal control, allow the aeroplane to sink on to the ground, due to loss of engine power, and trust that it will make contact more or less in stalling attitude. If, however, he is 20ft. to 30ft. up, he may attempt to put the nose down and induce a kind of glide from which he may hope to flatten out in the usual way. He must remember that the aeroplane will be sluggish in answering to the longitudinal control, that after engine failure it will begin to sink rapidly, and that if it answers sluggishly to the longitudinal control and only starts putting its nose down as it approaches the ground, there is no hope of flattening out; it were better that the pilot had attempted to keep flat from the moment of engine failure and trusted that the stalling moment of the elevators would be sufficient to hold in check the nose-diving couple until the wheels touched. Just whether or not the pilot will decide to put his nose down when the engine fails close to the ground is a critical test of his judgment.

If the engine fails towards the end of the third phase of getting off, the pilot has to choose between going straight on or attempting a backward turn. This has been discussed in Part II., para. (3). It was noted that if the pilot does elect to turn back, it is safer to dive and gain speed before commencing the turn than to commence the turn and try to gain speed while turning. It was a part of the teaching of the Gosport School of Special Flying, which initiated the modern conception of aerial manœuvre, that if the engine failed and the pilot judged that he could turn back, it was safest for him to dive down and carry out the banked turn with his inner wing tip close to the ground. If then at any moment his available margin of speed disappeared, he could effect a landing without the risk of a nose dive.

Lastly, if the engine fails when the pilot is well up, the first phase of landing may be said to commence when he puts the nose down and commences to glide. From this moment he manœuvres for position by gliding towards the most open-looking stretch of country. On the whole it is not worth while, except in a very wide sense, selecting a landing place from above 5,000ft., as local features are too obscure; and once the pilot has committed himself to the idea of landing in one place, it is disturbing to be compelled to change his mind later on. If possible, the pilot should attempt to arrange his glide so that he will pass over the selected landing place at an altitude not exceeding 2,000ft., to enable him to make one good inspection. This he can do by gliding over it down wind. After that the general idea will be to approach the landing space with a margin of height to avoid the risk of undershooting, and lose this height by manœuvre.

Every pilot has some particular way of manœuvring to lose height that he considers safest and most efficacious.

The simplest way, if the field has breadth at right angles to the wind direction, is to make use of this breadth by approaching the field just short of one edge at right angles to the wind. The pilot has then a certain latitude of time in which he can turn up wind, during which time he is losing height and is yet within range of the landing space. He can further assist his rate of losing height before turning up wind by sideslipping in the down wind direction. The wing farthest from the landing space will then be depressed, and the turn up wind will help him off the sideslip, as in itself it ensures the lifting of the depressed wing in order to bank for the turn.

A method of losing height that was in greater vogue formerly than to-day was to approach the landing space with a margin of height and then lose it by a series of partial turns, first one way and then the other, usually termed S-turns. This method enables the pilot to lose height quickly, but it has disadvantages. Firstly, by the complication of the manœuvre, the pilot tends to become confused in his sense of direction; and secondly, it is difficult to execute turns with the engine off without unconsciously increasing the speed, due perhaps to the pilot's instinctive fear of lateral instability at low speeds.

A modification of this method gives a still more rapid method of losing height. Instead of carrying out properly banked S-turns, the pilot does flat turns, yawing the aeroplane violently from side to side, up to as much as 60 or 70 degrees from his line of glide. For each flat turn he gives a turning impulse with the rudder and uses the ailerons against instead of with it, allowing the yawing moment due to the ailerons to increase the flat turn; which virtually amounts to letting the aeroplane take charge and then recovering. The aeroplane loses height with surprising rapidity, but the margin of control is too small for anyone but an extremely skilled pilot to practise this manœuvre.

A method which has the advantage of being a steady even manœuvre is the "sideslip" landing. It commends itself as being effective, reasonably safe and not liable to confuse the pilot, who simply puts one wing down and maintains a steady sideslip, varying the steepness according to the rapidity with which he wishes to lose height. It is an advantage if he allows the aeroplane to slew slightly, so that as he glides down the depressed wing is forward of the raised wing; for the nose of the aeroplane is then not in front of his eyes as he looks down at the place he intends to land on, and allows him a particularly good view. When the aeroplane approaches the ground the pilot straightens it out and effects a landing in the ordinary way. A perfectly clean recovery from such a sideslip is not unattended with difficulty, and the pilot may find himself drifting sideways, due to imperfect co-ordination of his controls. Most undercarriages will not stand up to lateral loads of any magnitude, and it is peculiarly important that the pilot should make contact with the ground without drift. As a last resource, the pilot can drop one wing, thus causing sideslip the opposite way in order to neutralise the drift. If he does this with skill, he will effect a landing on one wheel without damage. After running a few yards, the aeroplane will sink down on its other wheel and come to rest in the normal way.

The above methods of approach have been detailed separately; the actual practice of pilots is very difficult to analyse; the way in which an experienced pilot loses height is frequently a combination of features peculiar to these methods that is influenced by local conditions, because every forced landing in a confined space surrounded by obstacles is a different problem.

The pilot may sometimes be compelled to land across wind if the landing space is narrow and the wind is blowing across it. He therefore finds himself drifting badly as he approaches the ground. The most effective way of neutra-

lising this is by the method referred to, *i.e.*, dropping a wing and landing on one wheel. There is still another method, which consists in putting on full rudder at the last moment before contact and inducing a flat turn towards the down wind direction, which has the effect of causing the aeroplane to skid sideways in the up wind direction and of tending to neutralise the drift. Owing, however, to the uncertain action of the rudder at such a low speed, this method is generally less effective than the previous one. Neither method, of course, is resorted to unless it seems likely that the undercarriage will collapse sideways if the drift is not neutralised.

On lightly loaded aeroplanes it is sometimes possible to make a very slow landing by producing a sideways skid close to the ground with the rudder and making a recovery just before contact, but on heavily loaded ones it is almost impossible.

If the pilot finds that he is running into bad ground towards the end of the second phase of landing, he attempts to spin the aeroplane round on the ground with the last of his rudder control. An emergency device on the tail skid, in the form of a sprag, might be of use under these conditions. Its braking action could be made so severe that the ground would be torn up and the rear of the fuselage possibly damaged. It would never be used under normal circumstances, but it might be useful in preventing the aeroplane colliding with an obstacle at the last moment, or turning over on its back in bad ground at the end of its run.

Should the pilot be compelled to land on undulating ground, a comparatively steep uphill gradient is easier to land on than even a gentle downhill one, unless the aeroplane has efficient wheel brakes. In order to land uphill, the pilot must leave himself a greater margin of speed with which to flatten out; the actual flattening out will also have to be of a violent nature.

In making a forced landing without engine from a great height the pilot's difficulties of judging the landing are increased. As he glides down he thinks in terms of thousands of feet, and, if he has no chance of flying round for a short time low down, he finds it difficult to think in terms of inches, just prior to contact. If he misjudges his glide he may have to pass over obstacles at a dangerously low speed, and as he finally approaches the ground he will find that the vertical component of his velocity is very large. The best thing for him to do is to concentrate the whole of his flattening out in a violent jerk at the last moment, using his elevator control to the full extent rather than attempt a gradual flattening out. Similarly, if he is compelled to glide at a very low speed to reach the safe landing place, he must practise the greatest economy with his control movements; the slightest unnecessary control movement means loss of height which he cannot afford when he is trying to eke out to the uttermost his fast disappearing margin of control.

Finally, if the pilot is compelled to approach ground on the surface of which it is impossible to make a landing in the accepted sense of the word, he will do best to keep a good margin of speed and control until the last moment, when he can expend this by pulling the nose up with a violent jerk, trusting that he will drop flat before the nose-diving couple comes into play. If he remains sufficiently cool, it should be possible for a pilot, by keeping his speed till the last moment and then jerking the aeroplane up on its tail, to place it on the sloping roof of a house. A longitudinal shock is bound to injure the pilot; if remembering that his wings will absorb a shock of extreme violence, he can avoid colliding with an obstacle nose on, he may then hope to escape severe injury. A simple example of this is the contrast between striking a tree nose on and allowing the nose of the fuselage to pass between two trees and so taking the whole shock on the wings.

There is a certain point after which it is impossible not to wreck the aeroplane; pilots so often lose their lives and those of their passengers in attempting the impossible by overstepping the margin of speed and control of the aeroplane

in the vain attempt to bring it down intact; in other words, once the pilot has decided that it is impossible to save the aeroplane, he must simply regard it as a shock absorber, and crash it, so far as possible, with the minimum risk to his crew.

PART IV.—EXPERIMENTS WITH MECHANICAL DEVICES TO ASSIST LANDING.

1. The "Palethorpe" Tail Skid.

People are apt to regard the present process of landing as a reasonably ordered sequence of events; I hope that to pilots of the future it will seem like a chapter of accidents. I have always felt that, so long as immunity from landing crashes is secured by a delicate mental organisation that may at any time break down, the aeroplane, as a commercial vehicle, will be open to criticism. Experiments have therefore been in progress for some time at the Royal Aircraft Establishment with a view to reducing the personal factor in landing. To assist the pilot in landing, Captain Palethorpe designed a special tail skid (see photograph). It took the form of a long skid attached in a similar way to the ordinary tail skid, and a dashpot was incorporated in its action. If the pilot glided down with a little engine so as to flatten the gliding angle, and partially flattened his aeroplane out prior to contact with the ground, the action of the long tail skid damped out the subsequent tendency to bounce. With this device Captain Palethorpe achieved some measure of success, and was able to make a remarkable demonstration of landing at night, with little or no ground illumination. His device was, however, rather a valuable aid to the pilot's judgment than a substitute for it.

2. The "Noakes" Ground Indicator.

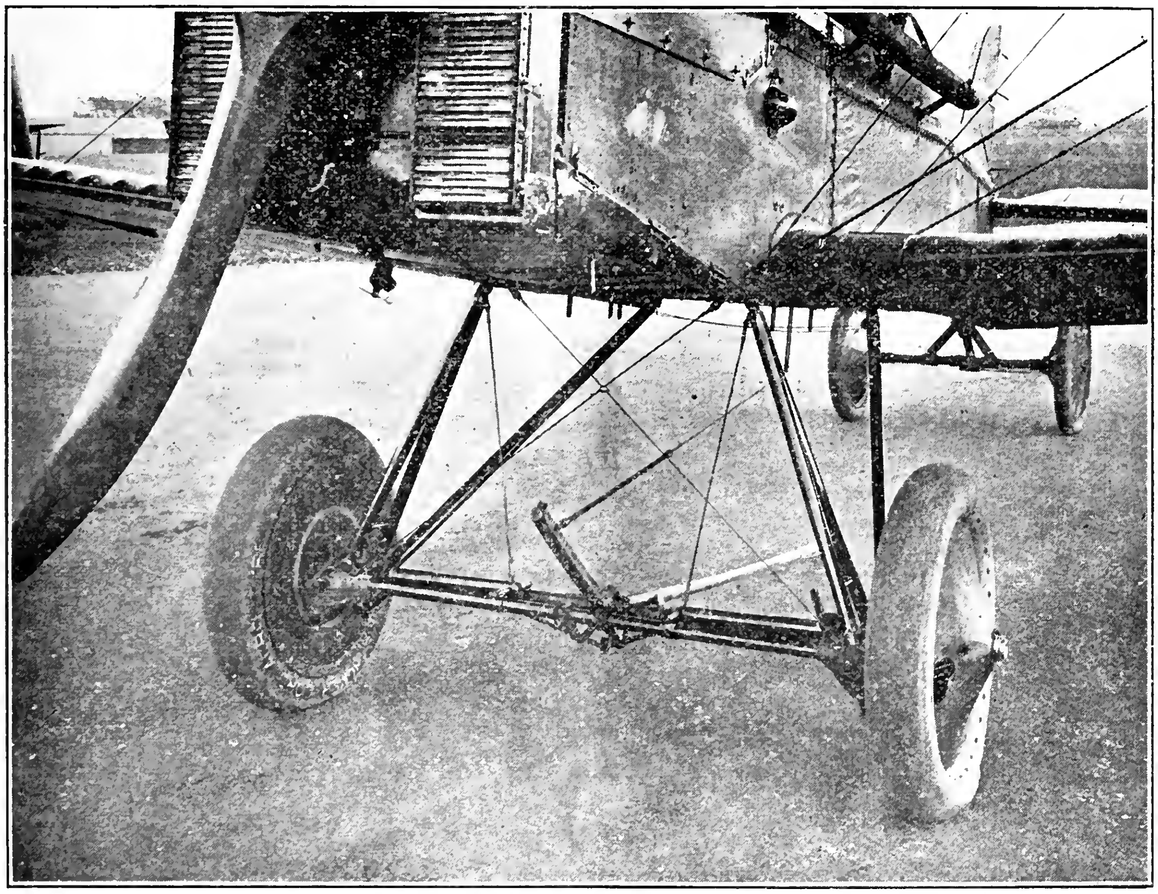
Flight Lieutenant Noakes, one of the most skilful exponents of manœuvre at low speeds, has subsequently carried out experiments with a device attached to the undercarriage of an S.E.5a (see photograph). It consists essentially of a long arm pivoted to a cross-member behind the wheel axle, and connected by elastic to the bottom of the control stick. This ground indicator is a device of a simple kind, and from its nature can only produce a simple movement. The elevator movements in landing are complex, but instead of trying to reproduce them, the device merely aims at substituting one or two simple operations for a complex effort of observation and judgment.

Extensive flying experiments have been carried out, and show the device to be a promising one. As the wheels of the aeroplane approach the ground the arm comes in contact with it, pulls back the control stick and flattens the aeroplane out. It has been found that landings can be made "hands off the control stick" if the pilot glides in with a little engine, and shuts it right off when the ground arm pulls back the control stick. Instead of curving up into the air again due to the stalling moment of the elevators, the aeroplane, because its engine is shut right off at the moment at which the elevators are automatically raised, sinks on to the ground in quite a good stalling attitude.

Now compare a landing with the indicator in action to an ordinary landing. In landing with the indicator, the pilot has certain definite operations to carry out, the performance of which is not based on an effort of rapid judgment. They are: the air-speed and engine revolutions at which to glide in, which are capable of being determined once and for all; and the moment at which to throttle right back, which is given to the pilot by the ground indicator when it pulls back the control stick. These are not obscure, but precise operations. Every landing without the indicator is a fresh problem, the successful solution of which is the result of long and habitual training.

Apart from the fact that the indicator is at a great disadvantage in a landing with engine stopped, efforts are being made to develop it further. Although

the pilot's instinctive elevator movements in landing are so complicated, it should not be impossible to study, analyse and reproduce them. For this purpose recording apparatus has been fitted to a Vickers Vimy in order that the elevator movements of landing may be investigated. A number of landings have already been made, records of which should form the basis for the contemplated development of the ground indicator. I am sanguine enough to hope that the pilot of a commercial aeroplane, provided that he has judged his entry into the aerodrome, and has set his aeroplane to glide at a steady speed, will be relieved of all further worry of landing. He will merely watch himself being landed.



The Noakes ground indicator.

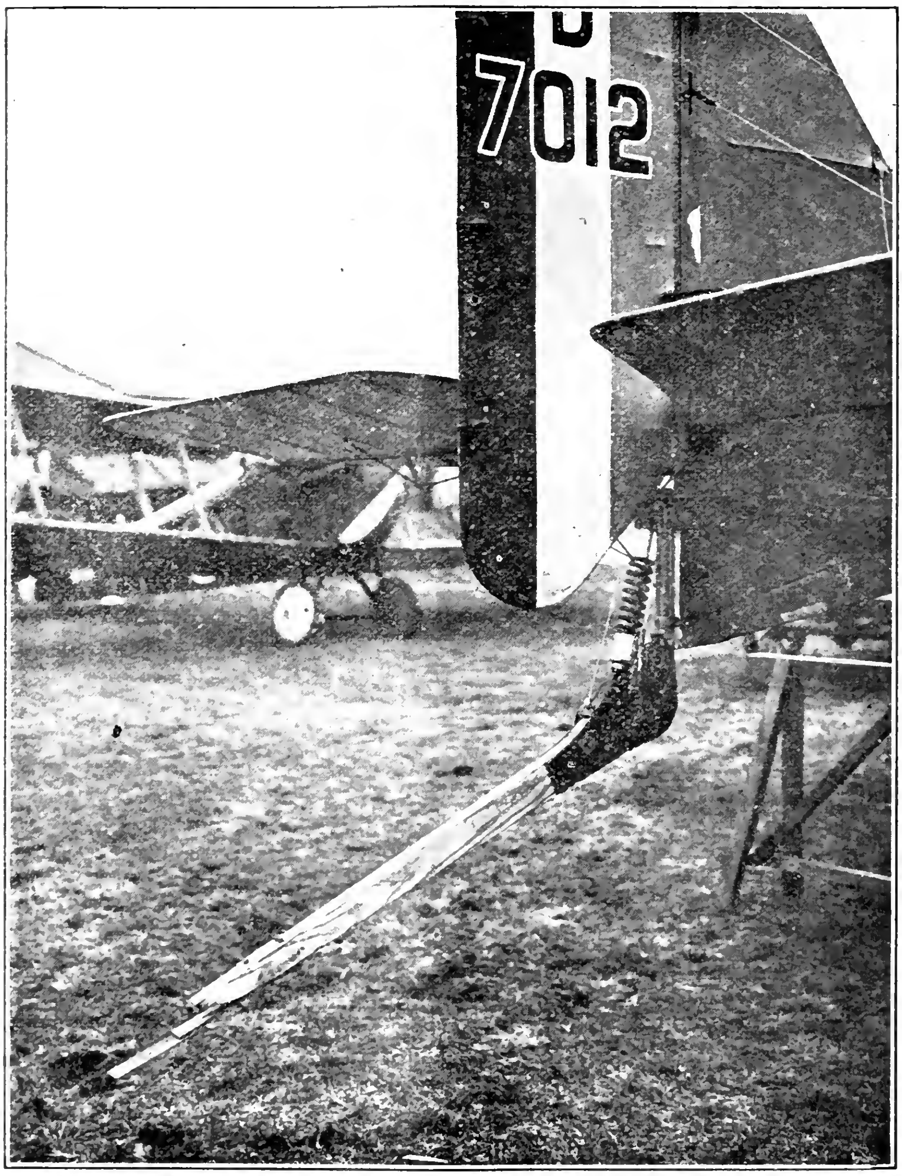
3. The Future.

The development of a device such as the Noakes ground indicator opens up the larger problem of approaching and landing on an aerodrome safely in thick fog or darkness. Even a sure means of flattening the aeroplane out at the end of its glide would avail the pilot nothing were he not certain ultimately to arrive at the correct place on the aerodrome. To this place the pilot must somehow be conducted. It has now been proved that aeroplanes can be flown in continuous mist or cloud by the use of the turn indicator, cross level, air-speed and compass. It is probable that in the future commercial aircraft will fly above cloud and mist up to heights of at least 10,000ft. There are, however, very few days in which the clouds or mist are not in layers. If the mist is right down to the ground, there should be some convenient height at which an aeroplane could fly and be above it. On the other hand, there is frequently a clear space of 500ft. to 1,000ft. between thick layers of cloud and the ground.

It seems perfectly reasonable that an aeroplane flying at 8,000ft. could be brought to a position above the aerodrome and informed of the nature of the clouds by wireless; that by means of a series of captive balloons let up through

the mist the pilot could be given the exact location of the landing space, and enabled to estimate the gliding angle necessary to bring him to the required spot; finally, that the aeroplane could be flattened out at the end of its glide by a mechanical device. To make this sequence of operations not only possible, but safe, will need many experiments; but success would widen immeasurably the possibilities of civil aviation.

Could we visit an air port of the future on a day when it was enveloped in creeping mist, I do not think we should find it deserted. On one side aero-



The Palethorpe tail skid.

planes would glide in, looming up like shadows; on the other they would get off every few minutes, only to be blotted out in the mist. There would be no fuss; simply the impression of perfect organisation. I dare to conceive of an aerial liner, already a speck on the far horizon, overtaken by a swift aeroplane whose mission it will be to deliver a late mail. The mail carrier alights on it, after a short interval releases itself, and then comes flying home. A Sir Thomas Lipton of the future, having (against all regulations) alighted on and made fast to the upper deck of an aerial P. & O., may even invite himself to lunch with her captain; but that captain is still a very small boy.

THE DESIGN OF AEROPLANE CONTROL SURFACES, WITH SPECIAL REFERENCE TO BALANCING.

BY H. B. IRVING, B.SC.

In a recent article in "Engineering"* the writer has given an account of the principles which govern the design of aeroplane control surfaces, making special reference to wing ailerons. Included in the information presented were data on the properties of wing ailerons of the ordinary unbalanced form, but varying in span and chord length and fitted to wing tips of different plan forms. From these data several conclusions of practical importance were drawn, some of them finding general application in the design of control surfaces, and it may be useful to give a résumé of these before proceeding to deal with the balancing of control surfaces.

(1) All ailerons and elevators become relatively inefficient for movements above about 15° to 20° from the normal position, owing to a sudden reduction in the slope of the curve relating moment on machine with angle of aileron or elevator. For movements up to about 15° or 20° the moment is nearly proportional to the angle.

(2) Rolling moment or pitching moment per unit area of control surface decreases as the chord of the control surfaces increases. In the case of elevators on a tailplane of rectangular plan form, the actual pitching moment is nearly the same, for a given angular movement, for elevators of chords from 0.4 to 0.6 of the total tailplane chord.

(3) Hinge moment on unbalanced ailerons and elevators is roughly proportional to angular movement and to (area × chord) of aileron or elevator.

(4) Ailerons or elevators on a wing or tailplane having raked ends such that the leading edge is longer than the trailing edge are more "efficient" than those on a wing or tailplane having ends raked the reverse way. (Efficiency of control is defined as the ratio of the moment produced on the machine for a given movement of the control column to the effort required; comparison of efficiencies can only be made when the maximum control, that is to say, the maximum moment exerted on the machine, is the same in the different cases.)

(5) Maximum efficiency of control is obtained with ailerons or elevators of chord equal to about one quarter of the total chord of wing or tailplane. It may happen, however, that it is not possible to secure sufficient maximum control with elevators of these dimensions.

(6) The span of the aileron which gives maximum efficiency of control is about two-thirds of the semi-span of the aeroplane.

(7) The ailerons on the lower wing of a biplane are very slightly more efficient than the ailerons on the upper wing.

(8) Similar ailerons on both the upper and lower wings of a biplane are roughly twice as efficient as the same ailerons on the upper or lower wing only (the ailerons on one wing only being permitted roughly twice the range of movement of ailerons on both upper and lower wings, so that the maximum control is the same in the two cases).

(9) It is important that the gap at the hinge of a control surface should be kept as small as possible. In general, the effect of a gap at the hinge is to reduce

* October 8th, 15th, and 22nd, 1920.

the moment on the aeroplane which movement of the control surface produces, and, at the same time, to increase the hinge moment for small movements. The effect of a gap on the hinge moment is not nearly so marked as on the moment on the aeroplane, but the reduction of the latter may amount to as much as about 40 per cent. for a gap of half an inch on a total wing or tailplane chord of five feet.

By giving attention to the various points enumerated above, the designer may be able so to design the control surfaces of a fairly large machine that it is not unduly heavy on the controls, without resorting to the expedient of balancing, when otherwise balancing would be necessary. With increase in the size of the aeroplane, however, there comes a stage when even the most efficient unbalanced control surfaces become too heavy for the pilot's strength, and either balancing of the controls has to be adopted or control must be effected through some form of relay motor which performs the actual operation of moving the control surface. Various forms of relay control have been and are being tried, with promising results, but it is the opinion of the writer that, having regard to the relative simplicity and effectiveness of different methods of balancing the controls, and to the size of present day aeroplanes, a stage has not yet been reached at which it is profitable to employ relay control.

In the present paper it is proposed to discuss three methods of balancing, all of which have been adopted in varying measure in practice. These methods are:—

(*a*) The "horn" method;
(*b*) The method in which balance is obtained by hinging the control surface about an axis some distance behind the leading edge, hereafter termed the "backward hinge" method;
(*c*) The Avro patent method of balancing by means of a small plane placed above the (horizontal) control surface and forward of the hinge.

Before taking each of these methods in turn and discussing it, however, it will be as well to give some general consideration to the problem of balancing.

General considerations.

For geometrically similar aeroplanes at a given speed the force on the control column, or hinge moment required for a given movement of the controls, varies as the cube of the linear dimensions. Thus, for a machine which is, say, five times the size of a similar machine, the control surfaces must be balanced to such an extent that the hinge moment must be reduced to 1/125 of the unbalanced moment if the effort required for given settings of the control surfaces is to be the same in the two machines. This is, of course, an extreme statement of the case; for, generally speaking, the required proportion of control surface to total surface becomes less as the size of the machine increases. How much less it may become it would not appear to be possible to say definitely, in view of the absence at present of any specific information as to the requisite amount of controllability for aeroplanes of different types. Nevertheless, it is clearly seen that a very considerable reduction in hinge moment may require to be attained by "balancing" in a large machine, if the control is not to throw undue strain upon the pilot.

This being so, it becomes important to know how the amount of balance varies with the attitude of the aeroplane for any given system of balancing, in order to guard against the control members becoming overbalanced under certain conditions of flight and "taking charge" of the machine. Thus, consideration of the merits of different methods of balancing should include a study of the behaviour of the control surfaces at different angles of incidence and of yaw; and the effect on the balance of such manœuvres as a steeply banked turn, or a spin, should also be considered.

This paper will relate chiefly to the balancing of ailerons, and it should perhaps

first be explained exactly what is meant by the term "balanced" as applied in this connection. In the strictest sense, control surfaces may only be said to be balanced over a certain range of movement when the moment about the hinge of the control member is zero for all positions within the given range of movement. In the case of ailerons, however, which are always cross connected so that when they move downwards on one side of the machine there is a corresponding upward movement of those on the other side, the ailerons are balanced, *so far as the pilot is concerned,* when the algebraic difference of the hinge moments on the two sides is zero over a given range of movement of the ailerons. It will be "balancing" in this sense which is referred to in what follows.

The "horn" method of balancing.

By far the most common method of balancing ailerons is to have a "horn" or projection on the aileron beyond the wing tip and forward of the aileron hinge. It will be shown that there are several serious disadvantages attaching to this method, and that although it may be reasonably satisfactory for small aeroplanes, in which the degree of balance required is not great, the method is quite unsatisfactory, if not dangerous, when applied to the ailerons of a very large aeroplane, in which the object is to obtain a near approach to balance.

In the first place, it has been found that the degree of balance obtained with the "horn" method is very sensitive to slight changes in size and shape of the balancing "horn"; a very small addition to the "horn" may convert a practically unbalanced aileron to one which is very nearly balanced or even overbalanced. It would appear from this that when such variables as plan form and section of the "horn" and wing tip enter in, a designer is hardly in a position to design ailerons of this type to have any specified degree of balance, and the chances are that the ailerons as designed will actually be either overbalanced or very much underbalanced.

Another disadvantage attached to horn ailerons is the fact that they may give rise to tensions in the control wires which are large compared with the tensions which obtain when ordinary unbalanced ailerons are used. It has been found that with the latter the variation in hinge moment on an aileron with angle of incidence is not great, owing to the fact that the direction of flow near the aileron to a large extent follows the lines of the wing section regardless of the angle of incidence. With the projecting "horn" of an aileron, however, the case is different. The "horn" is not in the downwash of the wing, and as the angle of incidence of the wing increases so does the angle of incidence of the "horn," and at about the same rate, exerting an increasing moment in the opposite direction to that on the main portion of the aileron. This goes on until the "horn" reaches a critical angle, above which the force on the horn no longer increases, and the centre of pressure recedes towards the hinge, causing a very sudden reduction in magnitude of the balancing moment. The effect is illustrated by Fig. 1, which is taken from A.R.C.R. and M., No. 728,* and gives hinge moment on one aileron of the proportion shown, plotted against aileron angle. Each curve applies to a given angle of incidence of the wing, and it is seen that until the incidence of the aileron becomes large, the change of moment with aileron angle is comparatively small; that is to say, the ailerons are nearly balanced as far as the pilot is concerned. But at the same time the change of moment with wing incidence is seen to be great; it is roughly as great as the rate of change with aileron angle would be if the ailerons were ordinary unbalanced ailerons of the same span and chord. This means that there are large tensions in the control wires, even for the normal position of the ailerons, over a considerable range of angle of incidence; also it appears that the aileron is subjected to more

* "Investigation on Ailerons," Part IV. "The effect of yaw on the balance of ailerons of the 'Horn' type." By H. B. Irving and K. Batson.

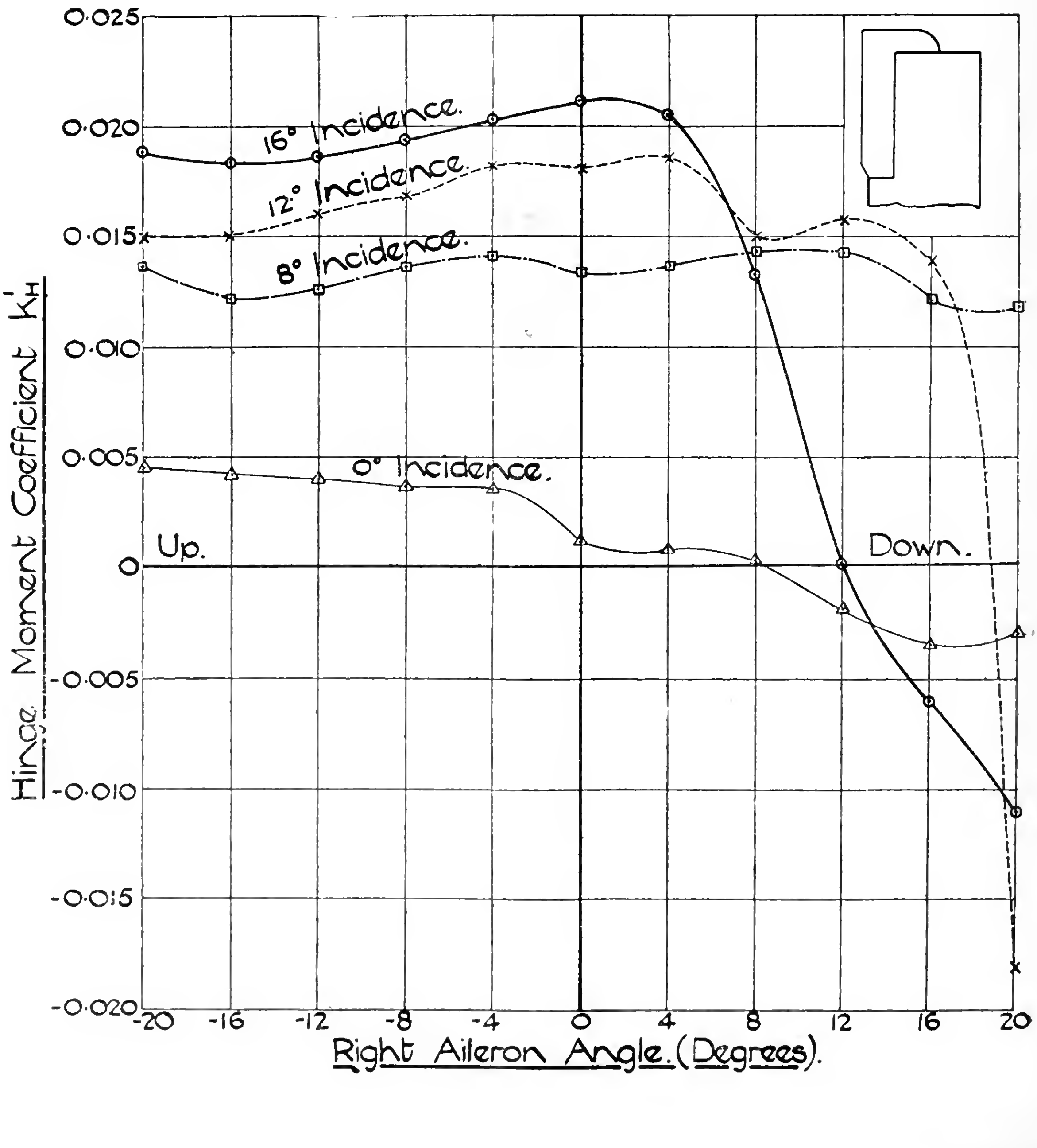
severe torsion than would be the case if it were unbalanced, and it is very difficult to make an aileron satisfactorily stiff against twisting action.

The actual balance of these ailerons, as felt by the pilot, is shown by Fig. 2, in which the algebraic difference of the moments on the ailerons on the two sides of the machines is plotted against aileron angle. It will be seen that until large angles of incidence and large aileron angles are reached there are no great changes in the balance; at angles of incidence of 12° and over, however, the range of aileron angle over which the ailerons are roughly balanced becomes smaller and smaller until at 16° incidence the ailerons are very stable over most of the range of movement.

Effect of yaw on "horn" ailerons.

As a result of flying experience with "horn" ailerons it was suspected by the R.A.E. that certain undesirable effects which had been observed were due to the effect of sideslip or yaw. Special experiments were accordingly made on the balanced ailerons of Fig. 1 with a view to investigating the effect of yaw on the balance of "horn" ailerons. The results of the experiments, which are given

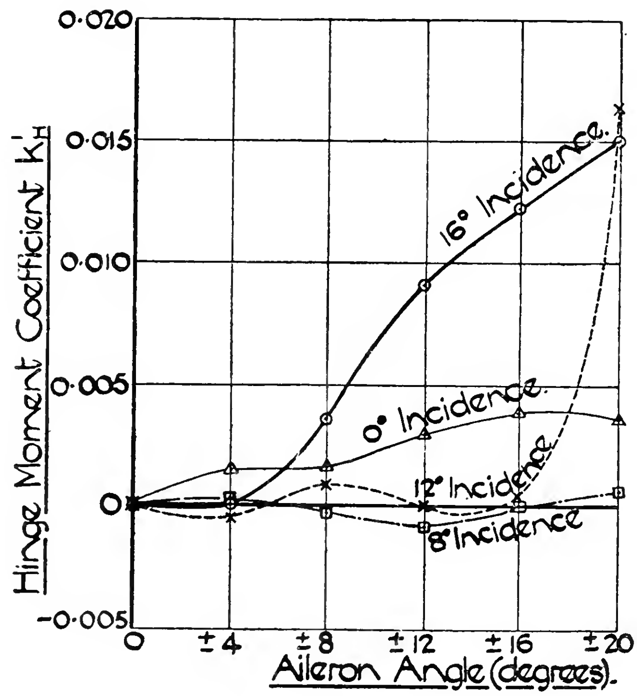
FIG. 1.



in A.R.C.R. and M., No. 728, showed that the effect of yaw was to make the ailerons overbalanced at certain attitudes over a varying range of movement of the ailerons; but whether or not yaw was the sole cause of the undesirable effects experienced in any operation involving turning could not be stated with certainty, because it was also found from the model experiments that there would be a tendency for the ailerons to take charge when turning in a small circle without sideslip, and a possibility of their taking charge when going into or during a spin.

It was found later that the above conclusions, based on model experiments, were borne out in a remarkable degree by previous observations made by Captain G. T. R. Hill during flying tests on an F.E.9 aeroplane with ailerons having a

FIG. 2.



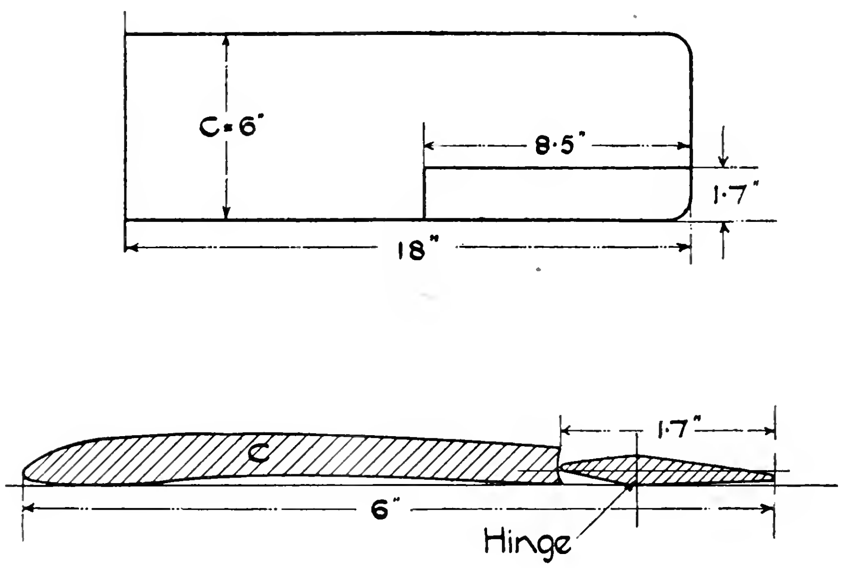
large pointed horn. The results of these tests are given as an appendix to the report on the model experiments previously mentioned. It may be of interest to give in Captain Hill's own words a description of the behaviour of the control column of the F.E.9 aeroplane under various conditions of flight:—

> " For ordinary straight flying and gentle turns the flaps are very good, though for stunting near the ground they are at present dangerous, even to an experienced pilot, as the amount of balance obtained seems to vary largely under different conditions.
>
> " If a steep turn to the left is started at 55 to 60 m.p.h. and 1,600 r.p.m., the speed cannot be kept below about 75 m.p.h. after a few seconds, and I was forced to push to the right with both hands and the rudder bar with my right foot with very nearly my whole strength in order to come off the turn. . . . Turning to the right the same feeling of the flaps taking charge is noticeable, though to a lesser degree.
>
> " The aeroplane was slowly stalled and spun to the right and the stick was held comparatively loosely; it was steadied rather than held, and lateral movement was free to take place if large force was applied to the stick by means of the ailerons. Just at, or about, the moment of stalling, as right rudder was being applied, and the stick was being quickly eased back and to the left, it suddenly flicked right over to the right, the aeroplane put its nose down and commenced to spin, and the stick immediately became quite

loose again and came over to the left, this being the position for spinning. The pilot has to resist an impulsive force of considerable magnitude to hold the stick across to the left while starting a spin to the right.

"When flying about level, hands off the stick, well throttled down at under 50 m.p.h., the aeroplane was trimmed gradually slower by means of the trimming wheel. As the speed approached within 2 or 3 m.p.h. of stalling speed, which is about 42 m.p.h., one wing, usually the port wing, would commence to drop slowly; the stick would then commence to move across to the left, thus giving more left bank and tending to exaggerate the amount the wing was dropping. The stick was quite heavy to pull to the right, instead of feeling very loose and sloppy like unbalanced ailerons feel when nearly stalling."

Fig. 3.



The general conclusion reached regarding horn ailerons is, then, that although they may be reasonably satisfactory for small aeroplanes, in which the degree of balance required is not great, and in which the moment is easily controlled even if the ailerons do become overbalanced under certain conditions, they cannot be regarded as at all suitable for large machines; in fact, they may even be dangerous if too near an approach to balance is made.

The "backward hinge" method of balancing ailerons.

In a recent research on the balancing of ailerons,* made at the National Physical Laboratory, experiments were made on a type of aileron which, it was thought probable, would not suffer from the drawbacks of the horn type and which, moreover, had been tried in practice by the Handley Page Company on their largest aeroplane and found to be satisfactory. In this type the aileron is balanced by placing the hinge back some distance from the leading edge of the aileron, the portion of the aileron behind the hinge conforming to the wing section, while the portion in front is shaped so as not to protrude, or to protrude only very little, outside the wing section when the aileron is moved up or down, as illustrated in Fig. 3. Possible variations of the method are illustrated in Figs. 4a, b and c. Fig. 4a shows the type of aileron adopted by the Germans in one of their Albatross fighting machines; Fig. 4b the type adopted in the Flugzeubau Friedrichshafen Bomber. In both these types the portion of the aileron forward of the hinge is

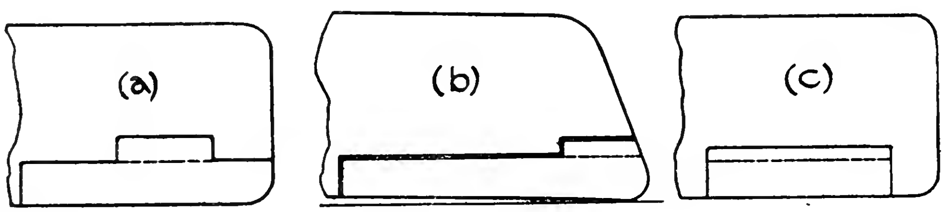
* R. & M., 651. "Investigation on Ailerons," Part III. "The balancing of Ailerons," by Irving & Ower.

not shaped so as to lie inside the profile of the wing section but conforms to it, so that movement of the aileron causes the portion forward of the hinge to project above or below the wing. The variation illustrated by Fig. 4c has not yet, so far as is known, been adopted in practice for balanced ailerons, but it is adopted in the "Panther" ship aeroplane for unbalanced ailerons. All the experiments were made on a 6in. × 36in. unstaggered biplane with "square" shaped wing tips, measurements being made of hinge moment and rolling moment. They were designed to give information on the following points:—

(1) Effect of variation of position of hinge.
(2) Effect of variation of angle of incidence of wings.
(3) Effect of yaw.
(4) Difference in balance of upper and lower ailerons.
(5) Effect of gap between nose of aileron and wing.
(6) Effect of ailerons, when in normal position, on the lift and drag of the wings.

For a full account of the experiments reference should be made to the report mentioned. The main results and conclusions are given, however, in what follows.

Fig. 4.



Variation of position of aileron hinge.

The first set of experiments was made on a series of ailerons having the hinge placed at various distances from the leading edge. For each position of the hinge the portion of the ailerons forward of the hinge was shaped so that when the ailerons were set at an angle of 15° up or down the lower or upper surfaces of the forward part of the ailerons were then flush with the wing surface.

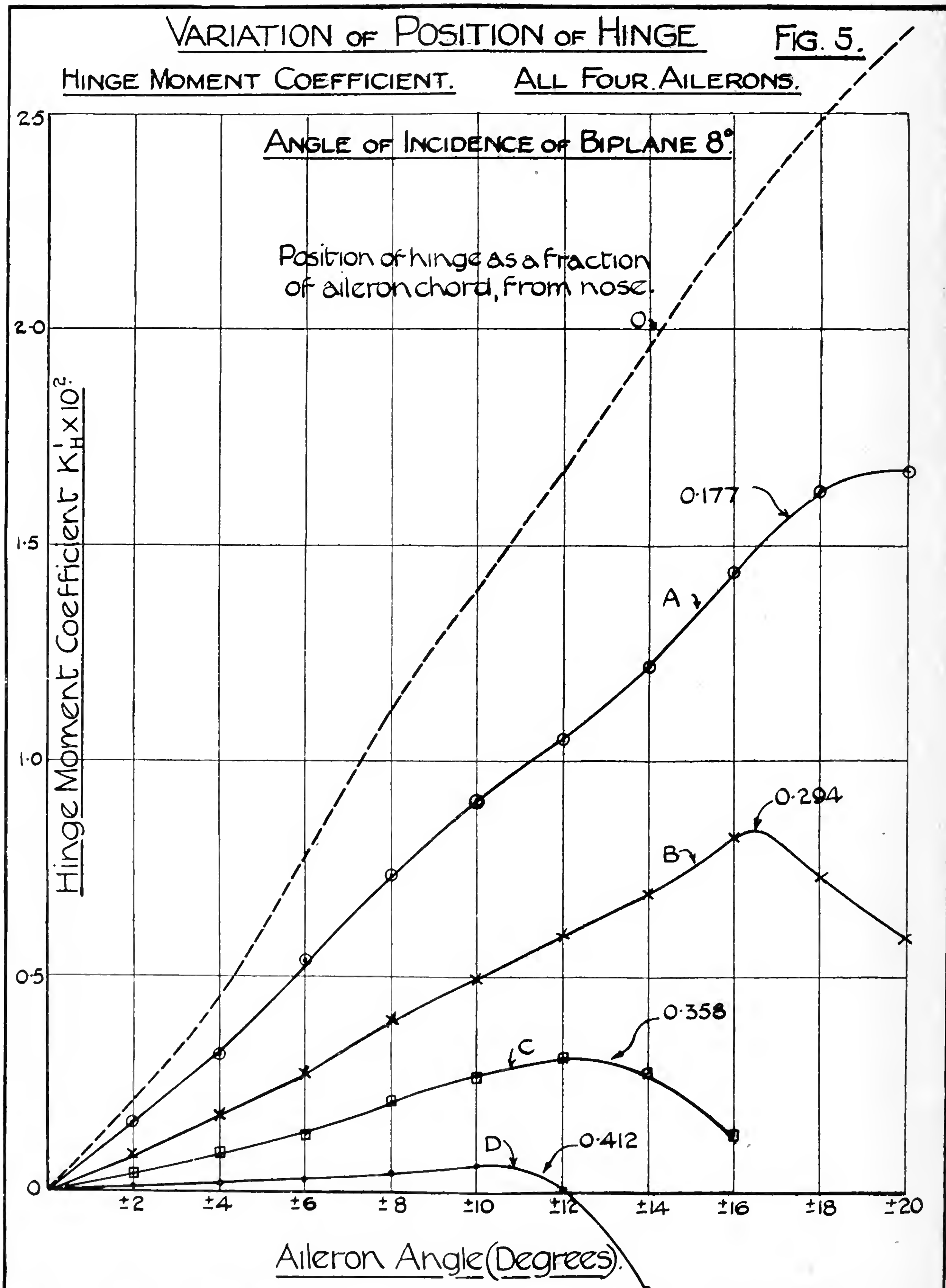
The resultant hinge moment on all four ailerons is plotted against aileron angle in Fig. 5 for the different positions of hinge. A curve obtained from estimation of the hinge moment for ordinary unbalanced ailerons is also plotted on this figure in order that the degree of balance which is obtained in the various cases may readily be judged. When the hinge is one quarter of the aileron chord from the nose the hinge moment is halved. Cross-plotting from these curves and slight extrapolation shows that when the hinge is at 0.425 of the aileron chord from the nose the ailerons become practically completely balanced up to an angle of about ± 10°, above which angle they become overbalanced. Ailerons of this type which are required to be very nearly balanced should therefore have a range of movement not greater than ± 10°.

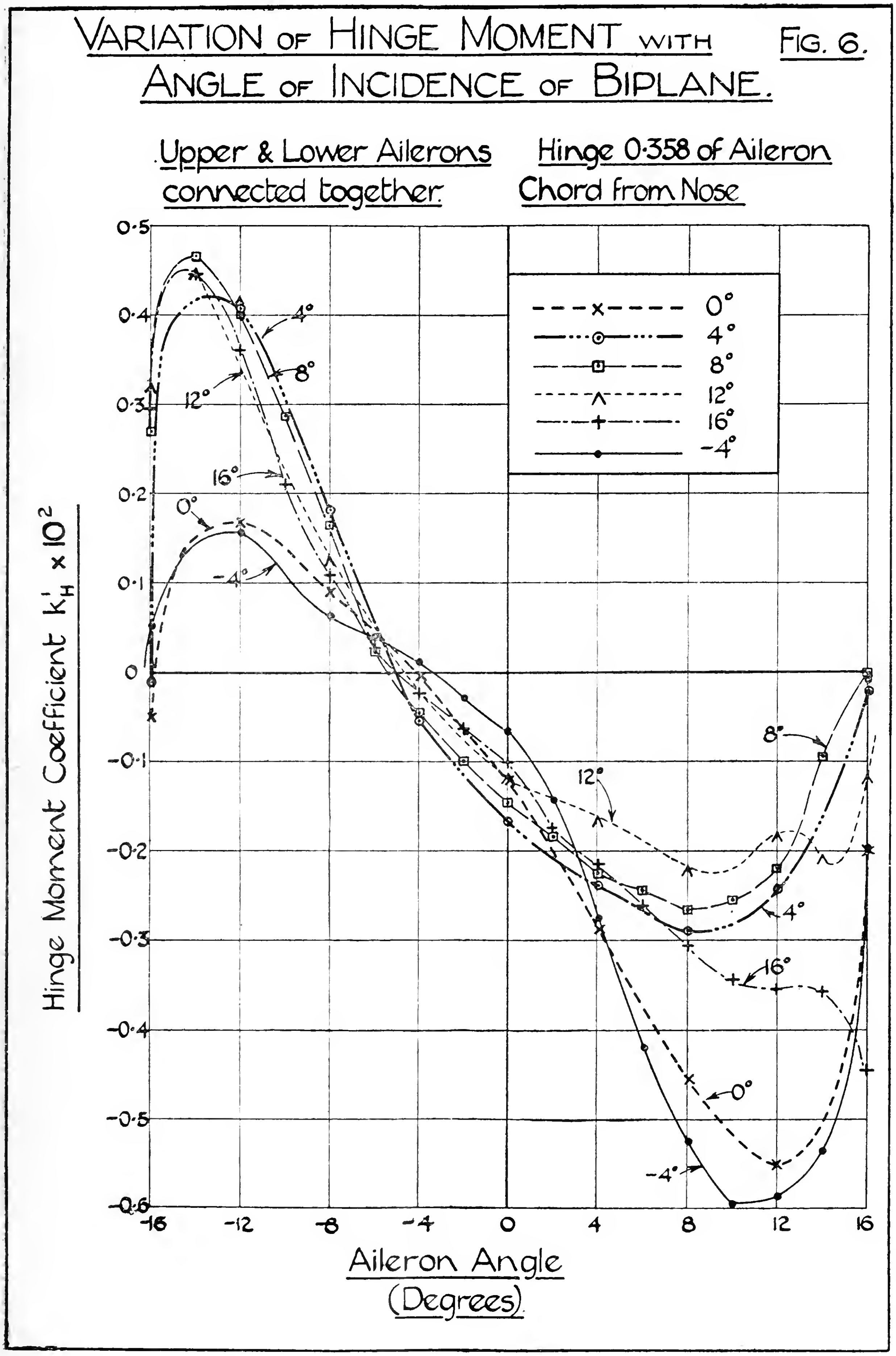
As regards rolling moment little need be said. Curves of rolling moment against aileron angle are practically straight lines over the working range of angle and there is a progressive decrease in the value of the rolling moment as the hinge is moved aft; the rolling moment due to the completely balanced ailerons is about 75 per cent. of the rolling moment due to the unbalanced ailerons of the same size.

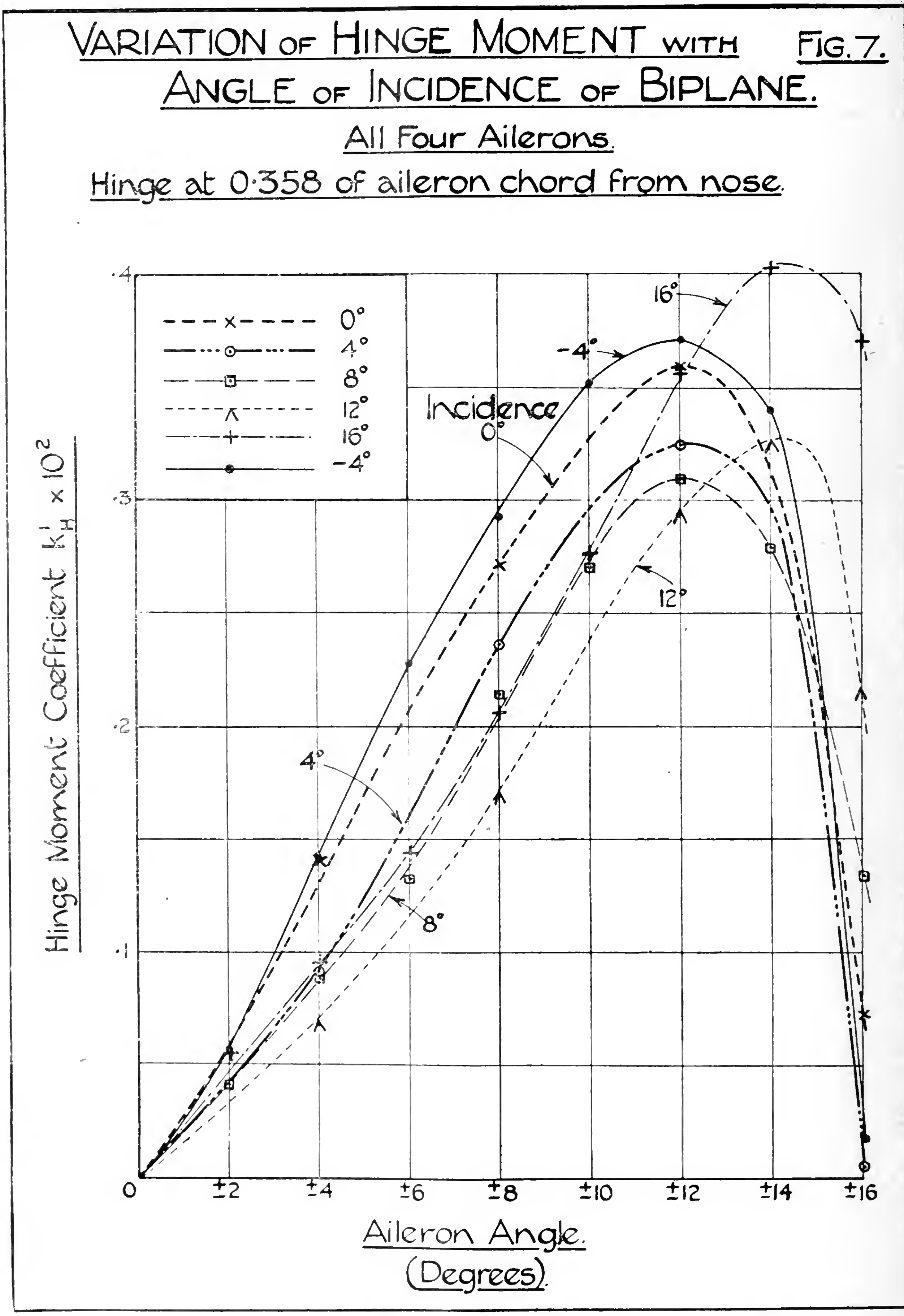
Variation of balance with angle of incidence of biplane.

The ailerons chosen for the tests on the effect of variation of angle of

incidence were those with the hinge at 0.358 of the aileron chord. In fact, in all the experiments subsequently described the hinge was in this position. Tests were made at angles of incidence —4°, 0°, 4°, 8°, 12° and 16° on upper and lower ailerons connected together. Hinge moment for the two ailerons on one side of the biplane is plotted against aileron angle in Fig. 6 and for all four ailerons in Fig. 7 for the various angles of incidence.




VARIATION OF HINGE MOMENT WITH ANGLE OF INCIDENCE OF BIPLANE.
FIG. 6.
Upper & Lower Ailerons connected together.
Hinge 0·358 of Aileron Chord from Nose
0°
4°
8°
12°
16°
−4°
Hinge Moment Coefficient $k'_H \times 10^2$
0·5
0·4
0·3
0·2
0·1
0
−0·1
−0·2
−0·3
−0·4
−0·5
−0·6
−16
−12
−8
−4
0
4
8
12
16
Aileron Angle (Degrees)


VARIATION OF HINGE MOMENT WITH ANGLE OF INCIDENCE OF BIPLANE.
FIG. 7.
All Four Ailerons.
Hinge at 0·358 of aileron chord from nose.
0°
4°
8°
12°
16°
-4°
Incidence
Hinge Moment Coefficient $k_H^1 \times 10^2$
Aileron Angle. (Degrees).
0
±2
±4
±6
±8
±10
±12
±14
±16
·1
·2
·3
·4

It will be seen from Fig. 6 that the variation in hinge moment with angle of incidence, for either upward or downward movement of the ailerons, is quite considerable. For about 12° upward movement the hinge moment at angles of incidence 4°, 8° and 12° is roughly double the hinge moment at —4° and 0° incidence; while for downward movement the reverse is true. Even so, the absolute variation of hinge moment with angle of incidence at a given setting of the aileron is quite small compared with the variation found in the case of ailerons of the " horn " type.

When the ailerons are cross connected the reverse effects of incidence, for upward and downward movements, to some extent cut out and the variation in resultant hinge moment becomes comparatively small as shown by Fig. 7. The curves of this figure show that from —4° to + 12° incidence there is a continuous decrease in the hinge moment, but the curve for 16° lies very near the curve for 8° incidence, except at the larger aileron angles, where it rises considerably above the 8° curve. Both the curves at 12° and 16° incidence reach their maxima at an angle of about 14°, whereas the other curves reach theirs at about 12° aileron angle.

At 10° aileron angle the variation in coefficient of hinge moment per unit area, k'_H, is from 0.0035 for —4° incidence to 0.0024 for + 12° incidence, a difference of 0.0011. It would appear probable that the absolute amount of variation in k'_H would not be much less for ailerons more nearly balanced than the ones under consideration. That is to say, the minimum value of k'_H at top speed of an aeroplane must probably be of the order of 0.0010 for ailerons at $\pm$ 10°, if the ailerons are not to become overbalanced at the speed corresponding to about 12° incidence; or, comparing this value with the corresponding value for unbalanced ailerons (Fig. 5), the maximum reduction of hinge moment feasible with this type of balanced aileron is about one-fourteenth.

Some idea as to what this means quantitatively may be given by a numerical example. Taking a large biplane with a wing chord of 15ft. and ailerons similar to those at present under consideration, fitted on both upper and lower wings, the hinge moment (corresponding to $k'_H = 0.0010$) required to move the ailerons through $\pm$ 10° comes out at about 280lbs.-ft. at a forward speed of 100 miles per hour. In a machine of this size the above figure might correspond to a force on the control column of about 28lbs. to be applied by the pilot, representing the minimum if the ailerons are not to become overbalanced at some speed below 100 miles per hour. It would appear then that with this type of aileron, hinge moment can be reduced to a magnitude which is within the pilot's strength even in the case of very large aeroplanes. Further, it should be noted that if there is any tendency towards overbalance it would occur at the larger angles of incidence and the lower speeds, when there would not be so great a danger of the ailerons taking charge.

The variation of rolling moment with angle of incidence is of a similar nature to that found for unbalanced ailerons. (See article in " Engineering," loc. cit.)

Balance of upper and lower ailerons separately.

Tests made to determine if there were any difference in the balance of upper and lower ailerons showed that the lower ailerons were very slightly more nearly balanced than the upper ones, the difference in hinge moment coefficients amounting to about 0.0005 at $\pm$ 10° aileron angle.

Variation of balance with angle of yaw of biplane.

The general conclusion drawn from tests made with the biplane yawed $\pm$ 20° was to the effect that, with the type of aileron under consideration, yaw has comparatively little effect either on hinge moment or rolling moment. Any effect

experienced was a reduction in both cases, but its magnitude was, in general, less than the variation of moment with angle of incidence.

Effect on balance of gap between nose of aileron and wing.

Attention has already been drawn to the fact that, in the case of unbalanced ailerons, even a small gap between aileron and wing considerably affected both rolling and hinge moments, particularly the former. Accordingly, as hinge moment is the quantity which is of primary importance in balancing, and as the effect of gap on rolling moment will almost certainly be of the same order of magnitude for balanced as for unbalanced ailerons, experiments on the effect of gap were made on hinge moment only; but further experiments, to be described later, were made on the effect of gap on lift and drag of an aerofoil, fitted with a continuous flap along the whole span, similar to the ailerons on the biplane.

In the case of unbalanced ailerons, the effect of gap at the hinge was to increase the slope of the curve of hinge moment against aileron angle, an effect which might have been predicted from the results of measurements of pressure distribution. Similarly, observation and deduction are in agreement as to the effect of gap on ailerons which are balanced, or nearly so, by the method under consideration; but in this case the effect is the reverse; gap makes ailerons which are nearly balanced still more nearly balanced. And the effect is, of course, relatively much bigger for balanced than unbalanced ailerons, as is illustrated by Fig. 8, which shows that a gap of 0.045 inches in a 6-inch chord almost halves the hinge moment.

In all the experiments hitherto described on balanced ailerons of the type now being considered, the rear edge of the wing was made with a radius appropriate to the position of the hinge of the aileron. It would be more convenient in practice to make this edge flat, in which case a gap, increasing in size as the aileron moved up or down, would be formed. The effect of such a gap could be estimated from previous results, but it was decided to make direct tests of the effect. The results showed the effect on hinge moment to be quite small (see Fig. 8) while on rolling moment there is a reduction which does not amount to more than about 13 per cent.

Effect of shaping the aileron nose and of gap on lift and drag.

In the first place it was desired to know what alteration in wing performance would follow as a result of shaping the ailerons, in the manner previously described, so that their portions forward of the hinge did not project above or below the wing when the ailerons were moved up or down. In the second place it was desired to know the effect of gap on lift and drag.

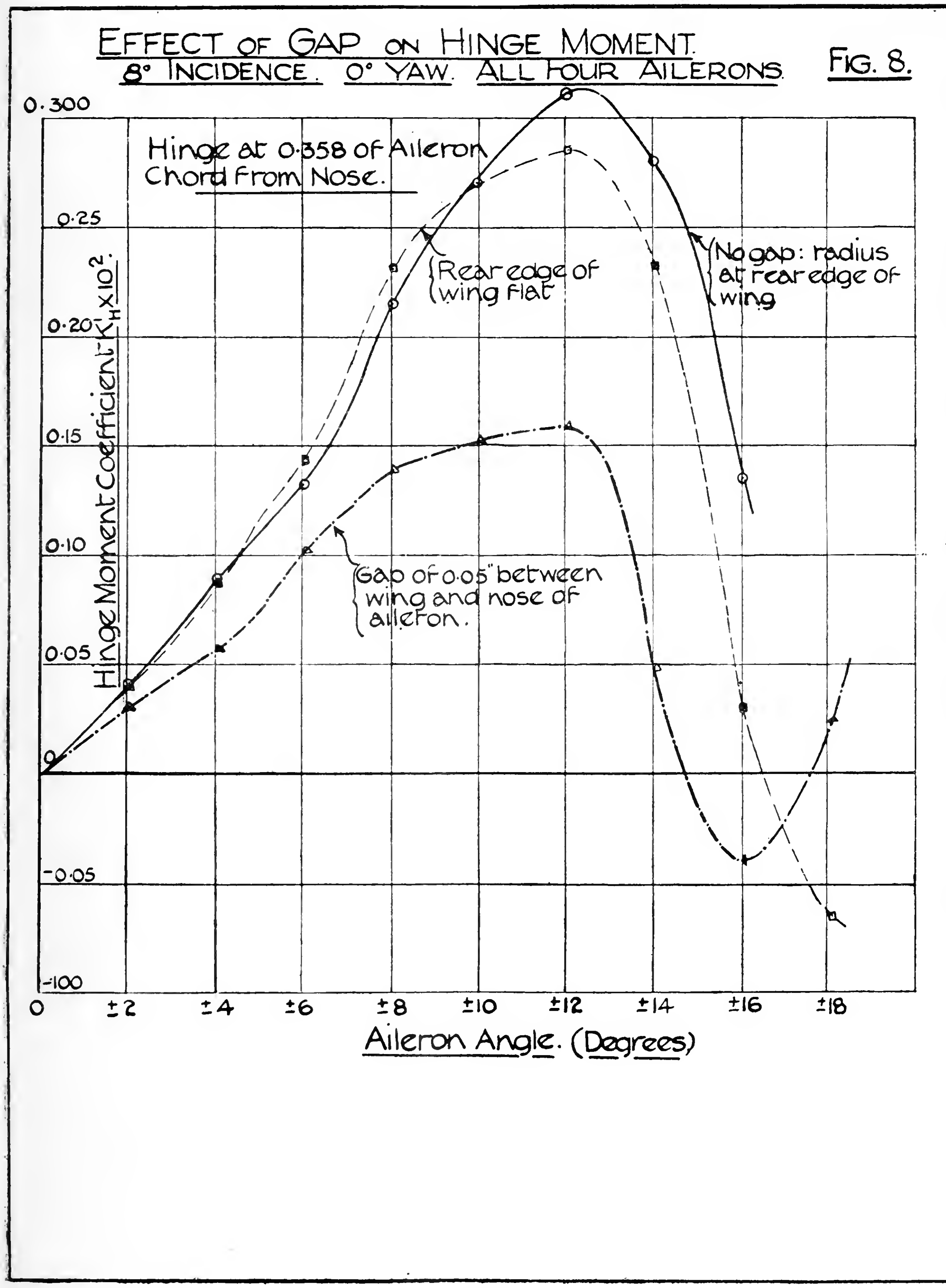
Both these effects were studied on an aerofoil of 6in. chord fitted with a continuous flap along the whole span, whose section was the same as that of the ailerons on which the majority of the tests were made. Lift and drag were measured in the wind tunnel in the usual manner with the flap in its normal position in the three cases:—

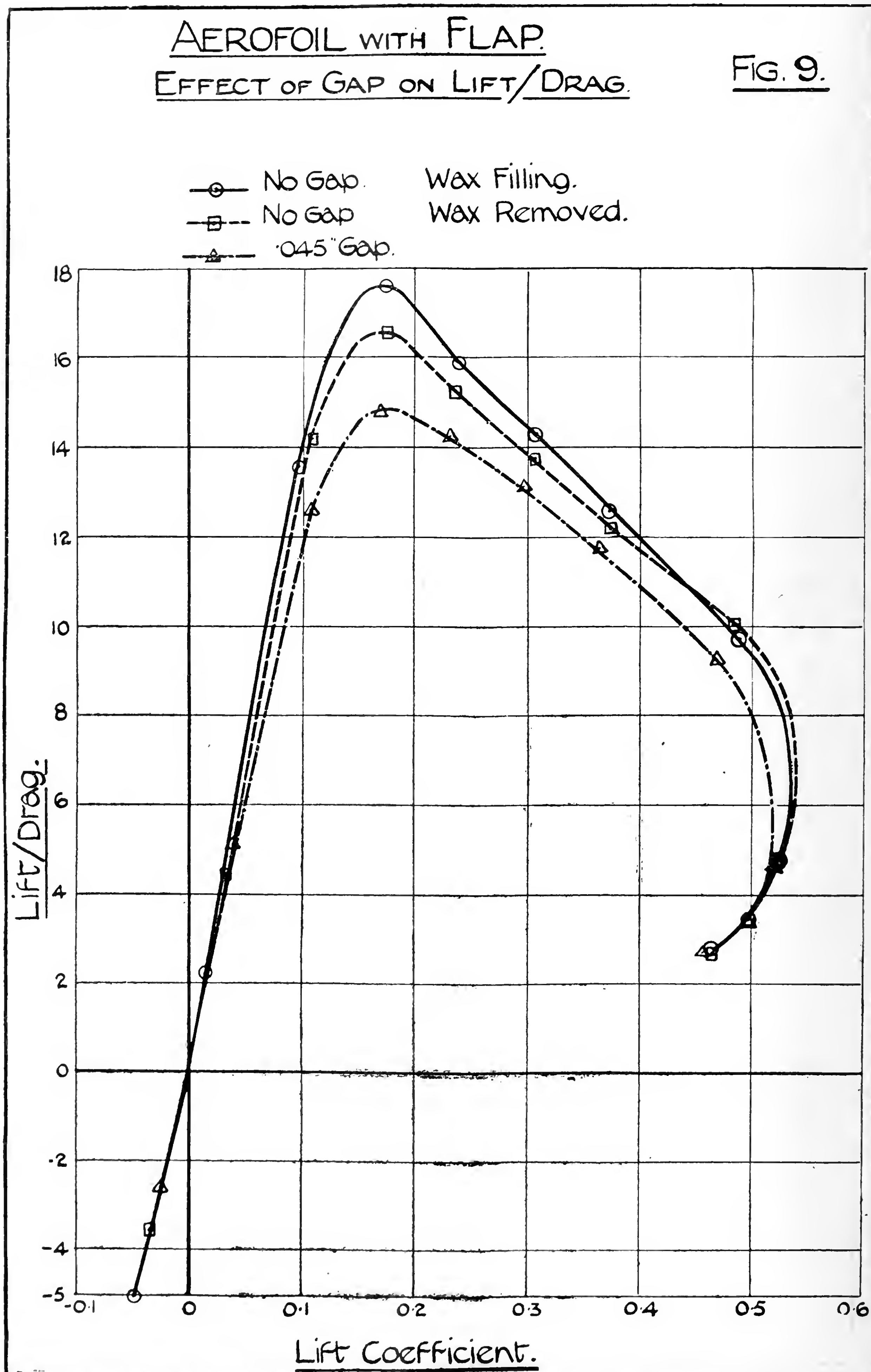
(*a*) Aerofoil made up to full section (R.A.F. 15 nearly) by means of wax filling.
(*b*) Wax removed.
(*c*) Flap adjusted to leave a gap of 0.045in. between flap and wing.

The results show that in both cases (*b*) and (*c*) lift is reduced while the drag is increased, both decrease and increase being considerably more in case (*c*) than in case (*b*); but in neither case is lift affected greatly. As for drag, the shaping of the ailerons increases minimum drag by about 3 per cent. and the gap increases it by a further 9 per cent. The combined effect on lift and drag is shown by

Fig. 9, from which it is seen that the maximum lift/drag ratios in the three cases (*a*), (*b*) and (*c*) are 17.6, 16.5 and 14.9 respectively.

It would appear that the reduction in efficiency of the wings due to shaping of the ailerons is not a serious matter, especially when it is remembered that the ailerons do not, in general, extend along the whole span of the wings.




AEROFOIL WITH FLAP.
EFFECT OF GAP ON LIFT/DRAG.
FIG. 9.
No Gap. Wax Filling.
No Gap Wax Removed.
·045" Gap.
18
16
14
12
10
8
6
4
2
0
·2
-4
-5
-0·1
0
0·1
0·2
0·3
0·4
0·5
0·6
Lift/Drag.
Lift Coefficient.

The reduction in wing efficiency due to gap, however, it would be well worth while either to eliminate or to reduce to a negligible amount by making the gap as small as practicable. It may be mentioned that the size of gap tested in these experiments corresponds to a gap which is slightly smaller than the actual gap measured on one of the Handley Page V. 1,500 machines, where it was as much as 1.2 inches. Such a gap as this would reduce the top speed by about a mile an hour and add a sum of the order of one hundred pounds to the running costs over the life of a machine.

Ailerons of full wing section, unshaped at the nose.

Before discontinuing experiments on the particular type of aileron under consideration, it was thought that it would be of interest to examine the behaviour of ailerons in which the full wing section was continued right to the nose of the aileron and to test if the position of the hinge for balance were greatly different from that in the case of ailerons with shaped nose.

The results were rather remarkable. Keeping the hinge in the same position as before, the ailerons, instead of being not quite balanced, were now decidedly overbalanced for angles up to about $\pm 8°$, where a very rapid change in the value and sign of the hinge moment took place, and the ailerons became more stable than ailerons with shaped nose. Accompanying the change in hinge moment there was also a rapid change in rolling moment. The slope of the rolling moment curve up to about $\pm 8°$ aileron angle was slightly greater than the slope for the ailerons with shaped nose. There was then a sharp fall in the rolling moment till it reached a value not much greater than half its value at 8° after which it changed only very slowly with aileron angle.

In view of the erratic behaviour of these ailerons, they hardly appeared to be suitable for adoption in practice, and no further experiments on them were made.

General conclusions.

The main conclusion to be drawn from the results of the experiments on ailerons balanced by the method described seems to be that this method should meet satisfactorily the requirements of the present day. If, however, there is in the future a still further large increase in size of aeroplane the method might fail; because in a very large machine the variation with attitude of the amount of balance of the ailerons might assume proportions so great—relative to the strength of the pilot—as to convert the ailerons of the machine from being easily controllable at one attitude to being either overbalanced or too heavy on the control at another attitude.

Ailerons balanced by the Avro patent method.

It is only comparatively recently that experiments have been made on a further method of balancing ailerons, namely, that patented by Messrs. A. V. Roe and Co., Ltd.; here again the method has been tried in practice and is stated to have been proved satisfactory. Balance is obtained by mounting a small balancing plane above the aileron, forward of the hinge, as shown by Fig. 10. which is reproduced from a photograph of the Avro "Manchester" aeroplane kindly supplied by Messrs. A. V. Roe.

The experiments were made on the same model biplane as was used for the experiments on the "backward hinge" ailerons, and with ailerons of the same size. A drawing of the wing with aileron and balancing plane used in the experiments is given in Fig. 11.* Only the upper aileron had a balancing plane attached,

* Taken from A.R.C. Report. R. & M. 696. "The balancing of Ailerons by the Avro Patent Method." By H. B. Irving and A. S. Batson.

as in the "Manchester"; the area of this plane is 14.6 per cent. of the area of two ailerons and nearly 2 per cent. of the semi-wing area. Measurements of hinge moment and rolling moment were made on upper and lower ailerons connected together, both with and without the balancing plane and its supporting arms in position, and at 0°, 8° and 16° angles of incidence.

Hinge moment per unit aileron area for upper and lower ailerons on one side is plotted for both cases in Fig. 12, the area taken in each case being the same, namely, the area of two ailerons without balancing plane, so that the curves give a comparison of the actual hinge moments in the two cases. From the positions where the curves of this figure cross each other it may be seen that for all three angles of incidence the moment due to the balancing plane is zero when the ailerons are about 8° up. As the balancing plane is set at an angle of + 7° with the wing chord, it would appear probable that the chord of the balancing plane should be set about parallel with the wing chord, if minimum drag of balancing plane and wing are to occur at the same wing incidence.

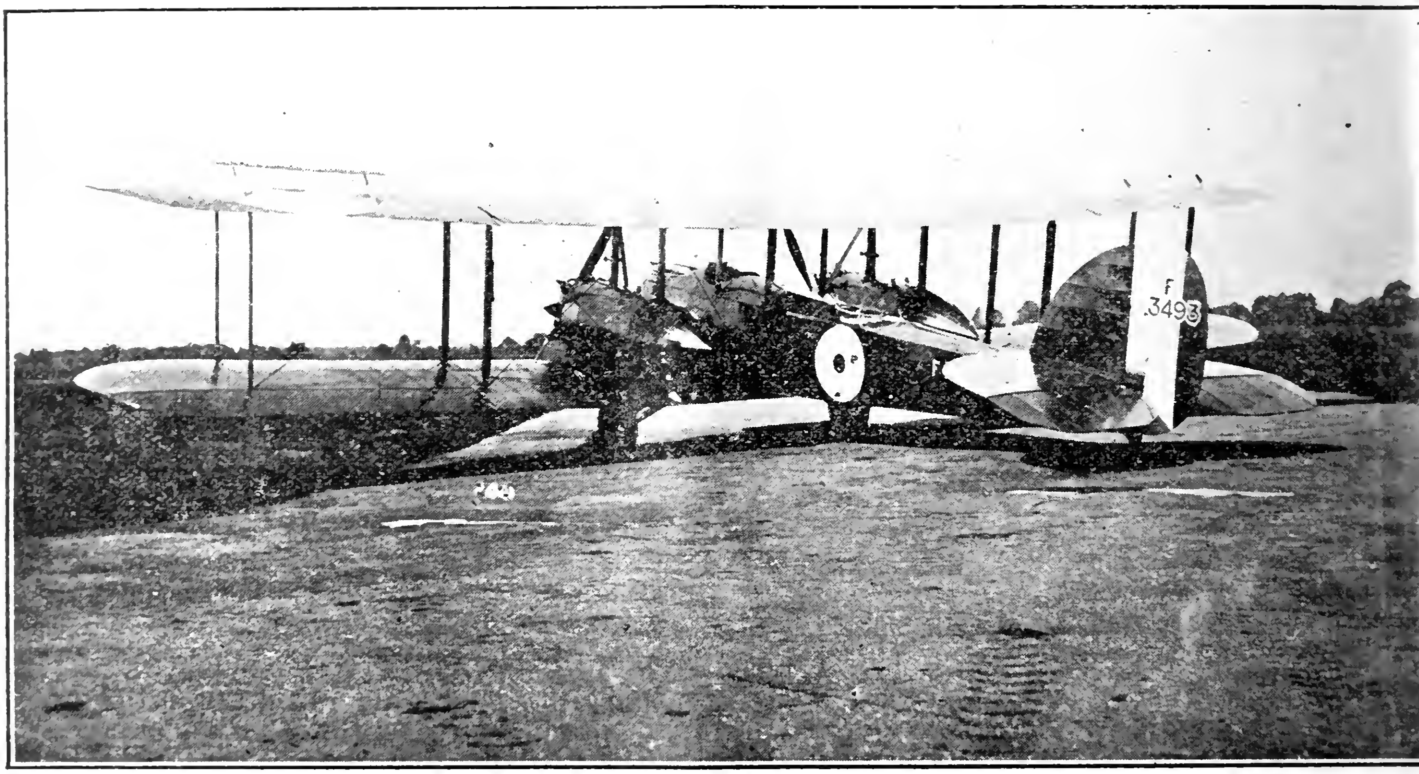


FIG. 10.—*Avro "Manchester" with small balancing plane.*

Hinge moment per unit aileron area is plotted for all four ailerons of the biplane in Fig. 13, which shows at once the reduction in moment due to the balancing plane. Expressed as a percentage, the reduction is greater for small than for large aileron movements; at ± 8° aileron angles the moment is reduced to about 65 per cent. while at ± 16° aileron angles it is reduced to about 75 per cent.

The curves of Fig. 13 also indicate that the degree of balance decreases as the stalling angle is approached, but not by so great an amount as to be important when the accompanying reduction in speed of flight is considered.

Assuming that a similar balancing plane fitted to the lower aileron would behave in the same manner as the balancing plane on the upper aileron, the addition of such a plane would make the ailerons balance to an extent about as great as designer would care to go. This degree of balance would be secured at a cost of about 5 per cent. increase in total wing drag, as against about 1½ per cent. by the "backward hinge" method of balancing.

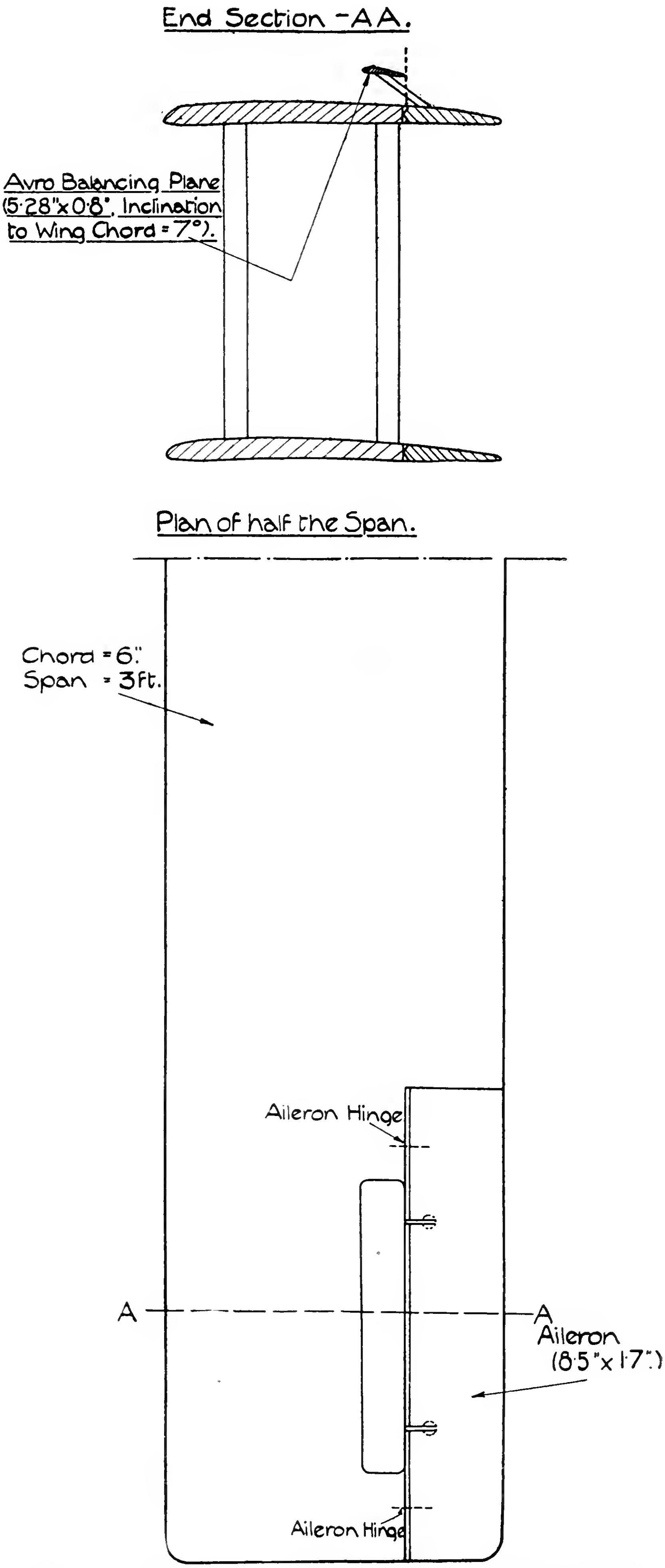


FIG. 11.—*Diagram of aileron with balancing plane.*

Balancing of rudders and elevators.

So far as the writer is aware, no systematic series of experiments have been made on the balancing of rudders and elevators. This would appear to indicate that the balancing of these control members is either not such a difficult problem or not so urgent as the balancing of ailerons.

As regards the relative needs for balancing the different controls as the size of the aeroplane increases, it is thought that the ailerons come first, followed by the rudder and the elevators.

Balancing of the rudder does not appear to present any very great difficulties. The "horn" method in this case does not suffer from the serious disadvantages which are met with in applying it to ailerons; but if it is desired to make a near approach to balance, this can hardly be done without experiments on the particular design in question. Further, the position of the balancing portion relative to the slipstream of the airscrews has to be carefully considered, since it is possible that if the balancing portion is in a region of higher velocity than the other portions the effect of the slipstream may be to make the rudder overbalanced.

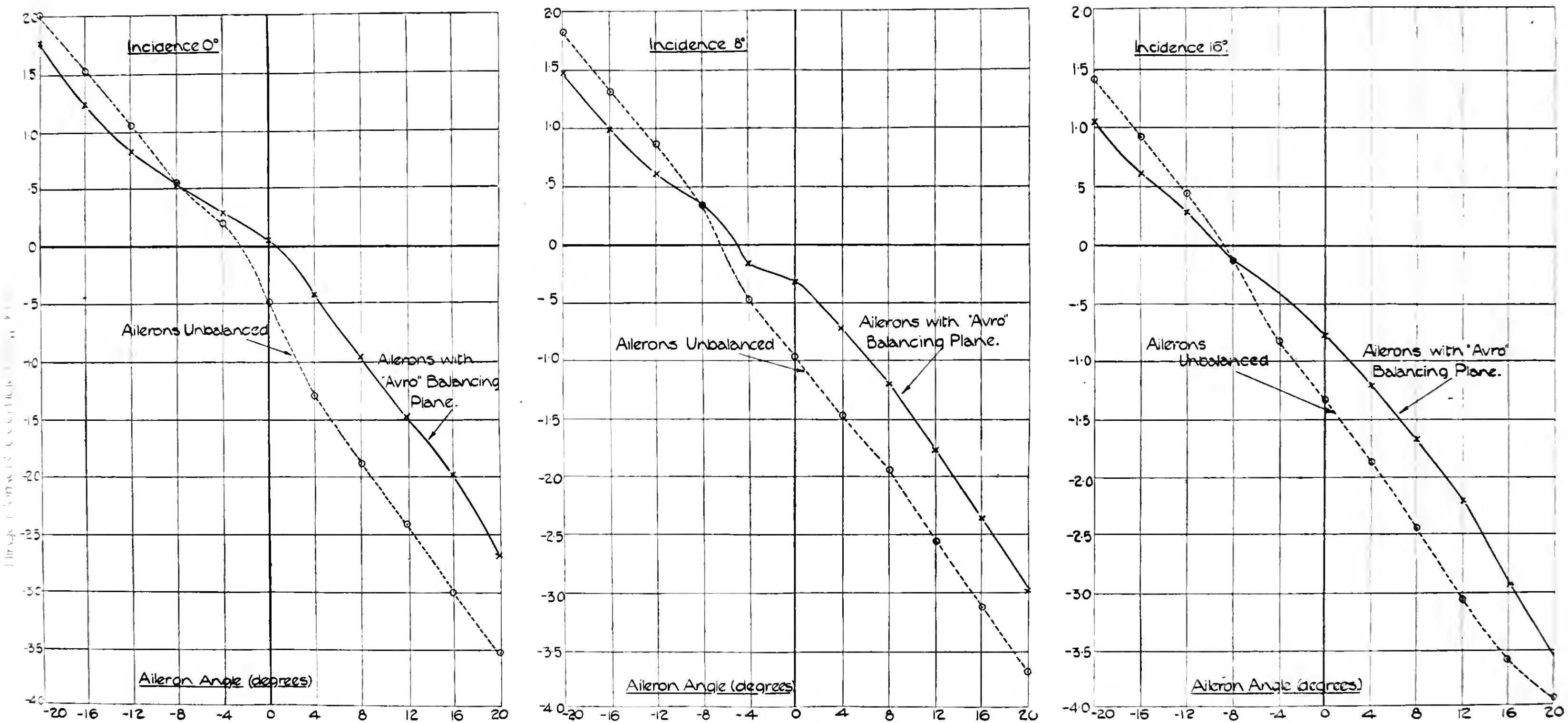
It is not clear that in the case of rudders there is any special need for methods of balancing alternative to the horn method. Should it be proved, however, that there is a need, it is quite possible that either the "backward hinge" or the Avro method could be successfully applied. The angular movement of rudders is usually considerably greater than that of ailerons; also the chord of a rudder is usually much larger compared with the thickness than is the chord of an aileron compared with its thickness. So that, if the hinge is placed backward some distance, only a small angular movement is required to bring the leading edge of the rudder outside the fin, making a gap and causing discontinuity in hinge moment with possible overbalance. But fins and rudders could be made thicker and of greater height so that the rudder would have a greater aspect ratio and could move through a large angular range without projecting beyond the fin.

With regard to the balancing of elevators, similar disadvantages apply in some instances to the horn method as apply in the case of ailerons. It has been seen that whilst it was possible so to balance an aileron that there was little or no change of moment on it with angular movement relative to wing, it was not possible by the horn method to avoid a large moment on the aileron as the angle of incidence altered. This did not affect the pilot, however, by reason of the cross-connection of the ailerons, but it would be of great importance in the balancing of elevators. The effect of the slipstream on the balance has also generally to be considered, as with balanced rudders.

As regards alternative methods to the horn method of balancing elevators, similar remarks apply to elevators as have been applied to rudders.

Hinge Moment for Two Ailerons.

Fig 12.



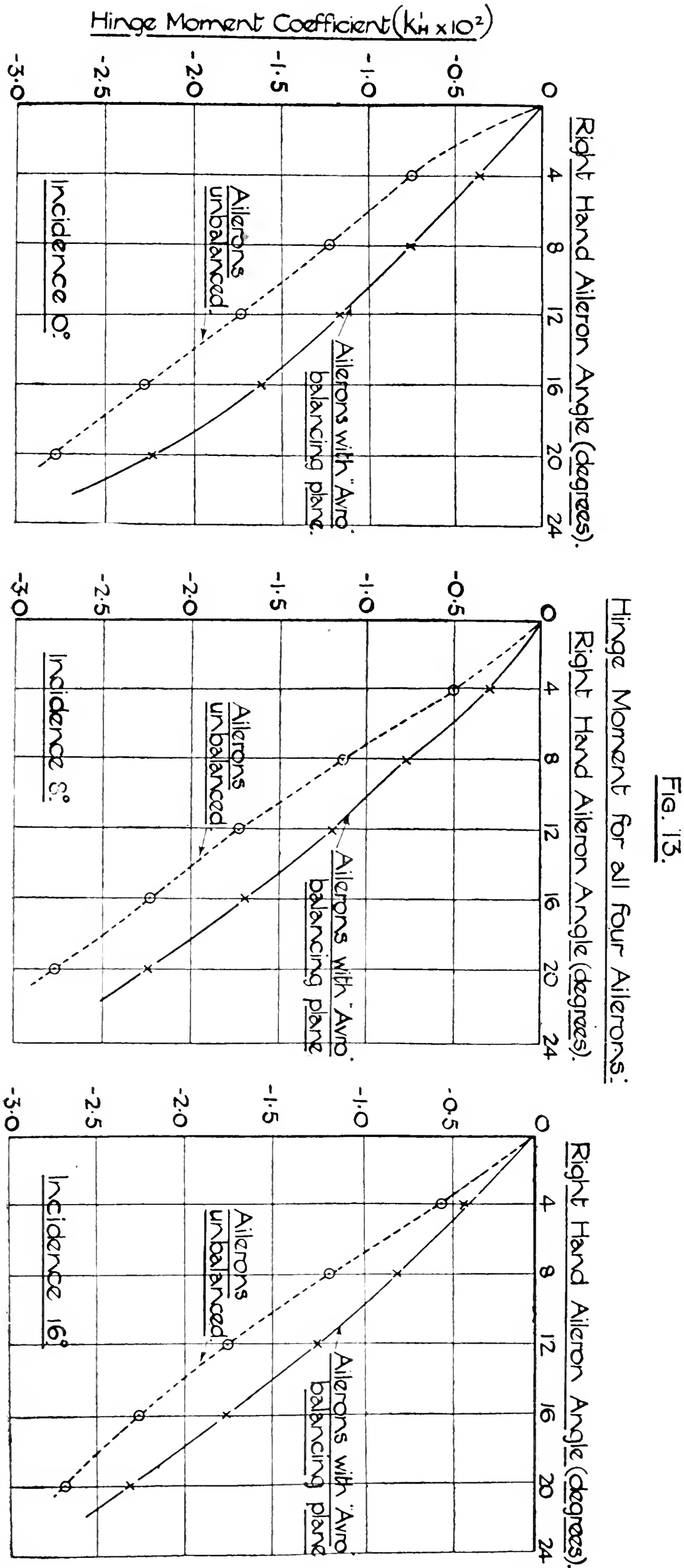


FIG. 13.

Hinge Moment for all four Ailerons:

STAGGERED SPAR SECTIONS.

BY H. P. HUDSON, M.A., SC.D., A.F.R.AË.S.

It has been suggested that strut fittings could be made neater, on a staggered aeroplane, if the spar web were given the same stagger. Then the principal axes of the section are not in the direction of either the loading or the supports. The result may be an increase of both bending and shear stress; not more than it is possible to provide for, but involving an increase of weight likely to be more than the gain in the fitting.

I.—BENDING.

The usual expression $\pm My/I$, for the stress at any point of a bent beam, assumes that the bending is about a principal axis of the section. If the loading is oblique, and M_y, I_z are the bending moment and moment of inertia about the first principal axis OZ, and M_z, I_y about OY, then the stress at a point of the section whose co-ordinates are y, z, is

$$M_y y/I_z + M_z z/I_y.$$

For a rectangular section, the worst stress is the sum of the worst stresses due to the two principal components separately, but for a section with rounded corners the worst stress occurs at the point of the section farthest from the neutral axis, which is at an angle

$$\tan^{-1}(M_z/I_y)/(M_y I_z) \text{ to } OZ,$$

and does not coincide with the axis of the resultant couple at

$$\tan^{-1}(M_z/M_y) \text{ to } OY.$$

If the spar section is unsymmetrical it may be more convenient to use axes which are not principal axes of the section. The expression for the stress is

$$\{ M_y(yI_y - zP) + M_z(zI_z - yP) \} / (I_y I_z - P^2),$$

where P is the product of inertia $\int yz\,dA$, which vanishes only for the principal axes.

But besides this, we may also have altered values of the component couples M_y, M_z. Consider an aeroplane spar of staggered section under vertical loading W. This causes deflection which is not in a vertical plane, but has a horizontal component, for which the intermediate drag struts, if any, are points of support, and which also produces loads in the ribs and a horizontal loading on the rear spar, which in its turn produces oblique deflection of the rear spar. If both spars carry loads in both directions, these all affect the component moments and deflections of either spar.

Let W_F, W_R, w_F, w_R be the lift and drag loads per unit lengths on the front and rear spars. Since there is an unknown transference of drag through the ribs, we do not know w_F and w_R, but only their sum w; but the horizontal deflections of the two spars are assumed the same at all points.

We must resolve in the principal planes in order to use the differential equations of bending in their simplest form

$$EI\,d^2y/dx^2 = M;$$

but in the vertical and horizontal planes in order to use the statical equations of moment in their simplest form

$$M = M_A - R_A x + \tfrac{1}{2}Wx^2,$$

in terms of the fixing moment and shear at the nearest support A; since the intermediate drag strut is a point of complete support against the horizontal deflection, but only of partial support in a principal plane.

Combining the equations, we arrive at the results

$$EI_z\, d^2/dx^2\, (y + zP/I_z) = M', \quad EI_y\, d^2z/dx^2 = m',$$

where M', m' are what the vertical and horizontal bending moments would be if the spar had its principal axes vertical and horizontal (the principal moments of inertia being still I_z, I_y), and loadings W', w', where

$$W' = W_F, \quad w' = I_y\, \{ w - W_F P/I_z - W_R Q/J_z \}\, /(I_y + J_y - P^2/I_z - Q^2/J_z),$$

and J, Q are the values of I, P for the rear spar.

Now M', m' can be obtained by any convenient form of the theorem of three moments. Hence the deflections y, z of the staggered spar can be found. At the middle of a lift bay the first approximations are usually taken to be

$$M' = W'L^2/8, \quad m' = w'l^2/12,$$

where L = distance between inflexions for vertical bending and l = length of drag bay.

For simplicity, we assume that $L = l$ = half the length of a lift bay, and also that the front and rear spars have the same section. The expression for the bending stress reduces to

$$(1/8)\, W_F l^2 y/I_z + (1/24)\, l^2\, \{ w - (W_F + W_R)\, P/I_z \}\, (zI_z - yP)/(I_y I_z - P^2).$$

If the section is obtained from a rectangle 4in. x 2in. by shearing it into a parallelogram of angle 60°, the ratio of the stress to that in the rectangular beam has the following values.

The spindled section has ½in. web and flanges measured horizontally and vertically. If the secondary bending strength of the rear spar is neglected, we obtain the ratios given in brackets.

Condition of Loading.	Stress Ratio.	
	Solid.	Spindled.
$W_R = 0$, $w = 0$	1·4 (1·8)	2 (3)
$W_R = 0$, $w = \frac{1}{6} W_F$	1·3 (1·5)	1·6 (1·9)
$W_R = \frac{1}{2} W_F$, $w = \frac{1}{6}\, (W_F + W_R)$ ...	1·5	2·05

II.—SHEAR.

If we use the expression for oblique bending stress given above, the usual method gives, for the mean shear stress σ across any plane cutting off an area A_θ on a base b_θ,

$$\sigma = (A_\theta / b_\theta)\, \{ \bar{y}\, (S_y I_y - S_z P) + \bar{z}\, (S_z\, I_z - S_y P) \}\, /(I_y I_z - P^2),$$

where S_y, S_z are the component shear forces and $\bar{y}$, $\bar{z}$ the co-ordinates of the centre of the area A_θ.

For a rectangular section 4in. × 2in., loaded diagonally, the worst stress is across a plane at 17° to the axis, and is about 5% higher than the stress across the narrowest way. For any direction of loading, there is one plane of no shear stress, which does not coincide with the plane of loading unless it is an axis or a diagonal.

For a square section loaded diagonally, the worst stress is at 23° to the other diagonal and is about 6% higher than the stress across the narrowest way.

For the upright I section, 4in. × 2in., web and flanges $\frac{1}{2}$in., with small values of the inclination a of the shear force to the vertical, the worst stress is very nearly the same as that across the middle of the web. As a increases, there is also considerable shear tending to cut off one flange at the root. The maxima of the two types are equal with $a = 33°$. For a given shear force the worst possible shear stress is with $a = 76°$, and occurs across the flange at $7\frac{1}{2}°$ to the vertical. It is 11% higher than that across the web in vertical loading and 4% higher than that across the flange in horizontal loading.

For the aeroplane wing considered, the component shears at any point are

$$-dM_y/dx, \quad -dM_z/dx,$$

which are found to be at A,

$$R'_A, \quad r'_A(1 - P^2/I_yI_z) + R'_AP/I_z,$$

omitting terms due to difference of fixing moments, we have the approximations

$$R'_A = W'l, \quad r'_A = \tfrac{1}{2}w'l.$$

Taking into account only the lift on the front spar, then with solid staggered spars the worst shear stress is 9% higher than for the rectangular section and occurs at $23\frac{1}{2}°$ to the horizontal. For the spindled section the corresponding figures are 16% and $32\frac{1}{2}°$. The shear across the flange is not considerable for normal conditions of loading.

The author's thanks are due to Miss H. M. Lyon, who has kindly verified these results.

CORRESPONDENCE.

To the Editor of the AERONAUTICAL JOURNAL.

SIR,—In Mr. Ritchie's interesting article on the effect of atmospheric pressure and density, there is one statement which requires correction.

It occurs on page 449, and is to the effect that the boiling point of water falls off approximately 5° F. for each 8,000ft. increase in height. It decreases very much faster than this, the actual rate being 1° F. in 535.5ft.

For further details see my "Notes on the Variation of Atmospheric Conditions with Altitude," published by the Munitions Inventions Department in 1919, and obtainable at H.M. Stationery Office for the modest sum of 6d.—Yours faithfully,

C. F. DENDY MARSHALL.

REVIEWS.

Meteorology. A. E. M. Geddes. (Blackie and Son, Ltd. 21s.)

The number of elementary text books of Meteorology is now reaching a considerable size, but Dr. Geddes' addition to this number is justified by the very much wider range of subjects which he covers, beyond those usually found in such books. Thus we find such diverse subjects as the temperature at the bottom of oceans; the composition of the air at great heights; sound ranging for artillery; the origin of the aurora, and meteorological optics, all touched upon in addition to the usual subjects of meteorological text books. This wide range of subjects makes it necessary to treat each rather briefly, the author's aim being to give a general review of the whole subject. It is therefore unfortunate that references to original papers and more detailed works on the various subjects are so few.

There are several paragraphs in the book which we would quarrel with, though these hardly affect its general character. On page 162 there occurs this remarkable sentence, dealing with cloud droplets :—" . . . . the droplets are solid, not hollow. For if they were hollow, the pressure inside, on account of their size, would be very much greater than that outside by reason of surface tension, and the drops would burst asunder." Now in the first place, we never knew anyone who supposed they were hollow, so that the statement seems rather unnecessary, but the latter part of the sentence is a truly remarkable physical deduction!

Again, on page 40 we find the following cryptic remark, for which the physical reasoning might have been as interesting as that above :—" The earth is not a regular sphere, but a spheroid, so that the attraction of the sun does not pass through the centre. The result is that the plane of the equator . . . is not that of the earth's orbit, the two planes intersecting at 23°."

Further, on page 57 the " greenhouse effect " (*i.e.*, the difference in the transparency of glass for visible and infra red radiation) is given as being the sole cause why a mercury thermometer exposed to the sun reads higher than true air temperatures. Does the author suppose that if the thermometer bulb were painted black on the outside, so that there was no " greenhouse effect," then a thermometer would always read true air temperatures even when exposed directly to the sun?!

The author's style is not always very clear, as instanced by the description of atmospheric pressure. In the opening paragraph of Chapter V., after discussing this subject, atmospheric pressure is finally defined as " either the elastic force or the weight it supports." Would the average reader's idea of atmospheric pressure be clearer, we wonder, after or before he read this definition?

These are but a few instances of many other somewhat unfortunate statements, which it is hoped the author will rectify in future editions; they do not, however, greatly affect the character of the book, which we hope will be useful to many.

Clouds. G. A. Clarke. (Constable and Co. 21s.)

Mr. Clarke is already well-known to meteorologists by the excellence of his drawings and photographs of clouds, and they, together with the general public, will therefore welcome this book in which he has reproduced between seventy and eighty of his cloud photographs and a few coloured drawings. The photo-

graphs are selected to illustrate all the various types of clouds, beginning with the highest cirrus and ending with the low nimbus. Some half-dozen of Capt. Douglas' photographs of clouds taken from an aeroplane are also added at the end.

There are five brief chapters at the beginning of the book dealing with the classification of clouds, the causes of their formation, etc., for the benefit of the general reader, and therefore of a semi-popular nature. Sir Napier Shaw also contributes a short paper. One excellent feature of the letterpress part of the book is that references to original papers dealing with the subject under review are constantly given, and are sure to prove very useful. Other writers might with great advantage follow Mr. Clarke's example in this matter.

Cloud photography is a special art, and one hardly ventures to criticise such a master of it as Mr. Clarke, but it appears as if most cloud photographers rather lose the sense of proportion. When one sees, for example, the finest cobweb-like cirrus shown as a hard contrast of dead white on a black background (a result made possible by the great development in modern plates and screens), one cannot but feel their eagerness to show every detail has somewhat overbalanced the wish to give a picture of the cloud as it really appears.

THE

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(FOUNDED 1897 in succession to the ANNUAL REPORTS.)

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Edited for the Council by J. LAURENCE PRITCHARD, Fellow.

All communications should be addressed to the Editor.

No. 131. NOVEMBER, 1921. VOL. XXV.

Notices of the Royal Aëronautical Society.

Election of Members.

The following members were elected at a meeting of the Council held on October 18th. Owing to various important matters which were on the agenda for discussion at that meeting, it is regretted that it was not possible to consider several applications for election to Associate Fellowship. These will, therefore, be considered at the next ordinary meeting of the Council:—

Students.—C. G. W. Ebbutt, W. S. Hollyhock, H. J. MacKintosh, N. S. Norway, C. A. Pike, F. Radcliffe, C. Russell, S. O. Smith, C. A. Wright.

Associate Members.—Mrs. J. E. M. Pritchard, T. Tateno.

Foreign Member.—T. Tanaka.

Students' Discussion Meeting.

The first Students' Discussion Meeting was held in the Society's Library at 7.0 p.m., on October 13th, with Mr. H. B. Irving, B.Sc., Associate Fellow, in the chair, when Mr. T. A. Kirkup opened the proceedings with a paper on "A Comparison of Different Types of Aerofoils."

At the close of the meeting the following gentlemen were appointed a Provisional Committee to undertake arrangements for the present session:—Mr. W. H. Rossiter, Mr. L. J. Jones, with Mr. Stanley H. Evans as the Honorary Secretary.

Donations.

The Council desire gratefully to acknowledge the receipt of a copy of "Strength of Materials," by G. Morley; "Aviation Engines," by V. W. Pagé; "Stability in Aviation," by G. H. Bryan; "The Diesel Engine," by G. J. Wells; and "Principles of Setting Out, Securing and Tooling Operations," by A. Parr, from Wing Commander H. Le M. Brock, D.S.O.; also a copy of "Theory of Airscrews," by A. Fage, from the Author.

Airship Photographs.

A letter has been received from the Director of Research, Air Ministry, notifying the fact that it has been decided to present to the Society for placing in the Library for the information of members ten books of airship photographs collected as a record of various types of airships that were used during the war, "in acknowledgment of the Society's activities in the cause of aeronautics, more especially with regard to airships."

R.38 Memorial Research Fund.

LIST OF DONATIONS TO OCTOBER 21ST.

	£	s.	d.
H.R.H. The Prince of Wales, K.G.	10	0	0
H.R.H. The Duke of York, K.G.	5	0	0
Rt. Hon. Lord Weir	105	0	0
Sir Alan Anderson	105	0	0
Messrs. Vickers, Ltd.	105	0	0
Lloyds, Royal Exchange	100	0	0
Council of the Royal Aeronautical Society	65	0	0
An American Sympathiser	25	0	0
Lady Shelley-Rolls	25	0	0
Flight Lieut. A. H. Wann	20	0	0
Mrs. E. M. Hilder	10	10	0
H. P. Marsh, Esq., J.P.	10	10	0
Staff of Royal Airship Works, Cardington	10	10	0
Lieut.-Col. W. Lockwood Marsh	10	0	0
Mrs. Waterlow	10	0	0
" From the Wreck "	6	10	0
Staff of U.S. Military Attaché	6	0	0
Lord Gorell	5	5	0
Mr. and Mrs. W. J. Anderson	5	0	0
Staff of U.S. Naval Attaché	4	10	0
Major C. C. Turner	3	3	0
Major G. H. Abell	2	2	0
Flight Lieut. F. M. Rope	2	2	0
Anonymous	1	2	0
Com. H. T. A. Bosanquet	1	1	0
Sir Charles Bright	1	1	0
" B. C."	1	1	0
E. R. Calthrop	1	1	0
Miss B. Haigh	1	1	0
Sir Samuel Roberts, M.P.	1	1	0
Major B. F. S. Baden-Powell	1	1	0
" J. T."	0	10	0
	£660	1	0

Arrangements for the Month.

Nov. 3, 5.30 p.m. Lecture by Squadron Leader R. M. Hill, M.C., A.F.C., on " The Manœuvres of Getting Off and Landing," Royal Society of Arts, Adelphi, London.

,, 10, 7.0 p.m. Students' Discussion Meeting, W. L. Le Page on " The Soaring Flight Problem," in the Society's Library.

,, 14, 8.0 p.m. *Scottish Branch.*—Lecture by Air-Marshal Sir H. M. Trenchard, Bart., K.C.B., D.S.O., A.D.C., on " The Auxiliary Air Force," Institute of Shipbuilders and Engineers, Glasgow.

,, 17, 5.30 p.m. Lecture by Colonel F. Searle on " The Requirements and Difficulties of Air Transport," Royal Society of Arts, Adelphi, London.

W. LOCKWOOD MARSH, *Secretary.*

PROCEEDINGS.

FIRST MEETING, 57th SESSION.

A meeting of the Society was held on Thursday, October 6th, in the Hall of the Royal Society of Arts, London.

Air Commodore H. R. M. Brooke-Popham said he was acting in a dual capacity, partly as Chairman of the meeting and partly as Lecturer. There was one pleasant announcement he had to make, and that was that Lieutenant-Colonel O'Gorman had been unanimously elected by the Council of the Society as Chairman for the ensuing year, commencing October 1st, and that he had accepted. He was sure they could not have a better choice than Colonel O'Gorman, on account of his long experience in aeronautics, his wide knowledge of scientific matters generally and also his charm of manner when he was Chairman of any meeting or committee. He would like to draw the attention of those present to a letter that had appeared in many of the daily papers on the previous Saturday on the subject of an airship memorial fund, called the R.38 Memorial Fund. The objects were pretty clearly set out in the letter, the point being to try and raise a fund for the continuation of research into airship problems, on however small a scale. There was no form of memorial that would have been desired more by those who had lost their lives in R.38 and previous airships than one of this kind, and he hoped they would be able to make it one worthy of them.

He would now take two paces to the right and become a lecturer.

Some months ago the Council had drawn up a beautiful series of lectures for the session, in which, to the relief of himself, and doubtless many others, his name did not appear, but whilst he was in a state of physical collapse, as a result of visiting tropical climates in the hot weather, he received a note from the Secretary saying the lecturer for that date had deserted, and that being unable to find anyone else he had to fall back on him.

Air Commodore Brooke-Popham then delivered the following lecture :—

AEROPLANES IN TROPICAL COUNTRIES.

1. I have recently paid a visit to Egypt and Mesopotamia with the object of finding out the particular troubles that are experienced with aeroplanes and engines in tropical climates. My stay in those countries only lasted for a total of 4½ weeks in July and August, and that, of course, is quite an insufficient time to get complete knowledge of the subject. In many cases I am afraid the information I shall give will be somewhat indefinite, but my main object is to indicate the troubles and leave their solution to other people.

2. First as regards the climatic conditions. The general impression I got was that, as regards the effect on aircraft materials, Mesopotamia was very nearly as much worse than Egypt as Egypt is than England, so that although one may get a solution for a particular difficulty in Egypt, it does not necessarily follow that the same solution will get over the difficulty in Mesopotamia.

At the end of the lecture are a few tables. No. I. shows the mean daily maximum and minimum temperatures for Cairo and Alexandria in Egypt.

No. II. gives figures indicating the relative humidity at London and Cairo, and you will notice the great variation at Cairo at different times of the day.

Table III. gives some figures for temperature and relative humidity at Bagdad, taken over an average of 30 years. You will see the differences in temperature are much higher than at Cairo, and they are somewhat trying to personnel as well as to material.

The figures for humidity cannot, I am afraid, be compared exactly with those given for Cairo, as they are taken one hour later, but there is no doubt that in the summer Bagdad is much drier than Cairo.

Table IV. gives some temperatures inside different types of building for various times of the day on July 21st, which was an unusually cool day.

The decrease in density of the air at Bagdad at midday in summer is roughly equivalent to starting at a height of 4,000 feet instead of at sea level, and in the case of most machines it means an increase of about 6 per cent. in the landing speed.

I did not do a great deal of flying, but so far as my experience went the eddy currents, etc., in the middle of the day were in no way so violent as to make flying dangerous, or even difficult for an experienced pilot, and I have certainly had far worse bumps during bad rain storms both in England and in France than when flying in Mesopotamia in the middle of the day.

This, of course, presupposes that one does not fly into a dust storm. These must be horrible, and the trouble is that they go up to very great heights in Mesopotamia, certainly over 12,000ft. at times.

Another thing that is disconcerting is the sudden changes of wind direction that one gets in the desert. On one occasion just after midday the wind, which was about 10 m.p.h. on the ground, kept changing 90 degrees in a few seconds, viz., from East to North and back again, and the smoke from a smoke bomb which was put out to give a guide to an unfortunate aeroplane trying to land, covered a segment of approximately 90 degrees instead of blowing in a straight line. About two hours later the wind suddenly died down completely, and five minutes afterwards began to blow steadily from a point a little south of West. One also gets sudden gusts, I suppose due to a small eddy; these are also liable to cause landing troubles.

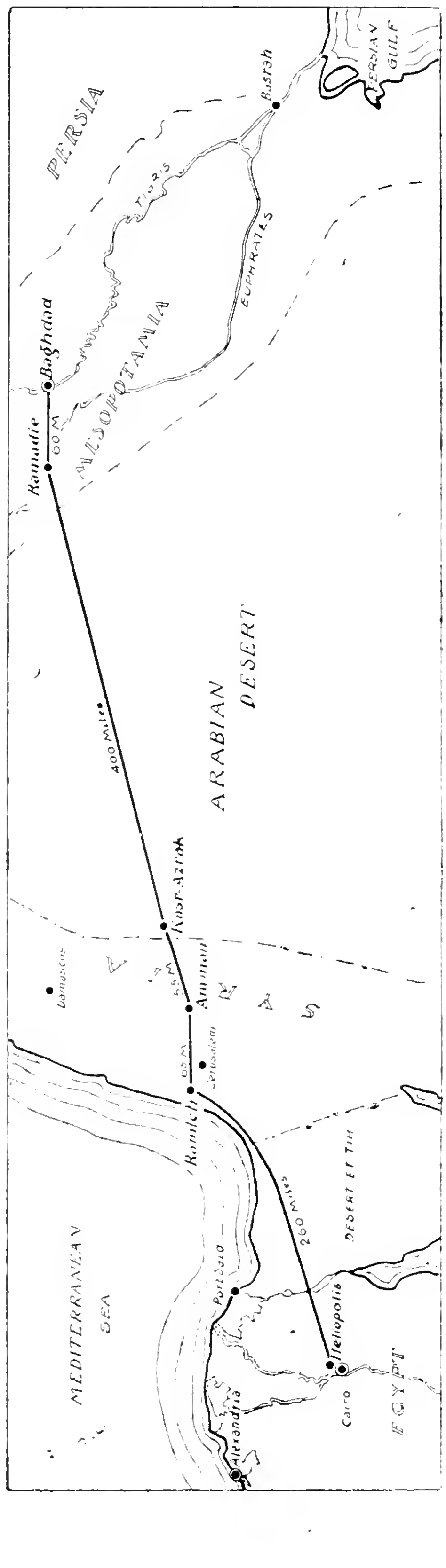
According to the records, whenever there is any wind at Bagdad it is nearly always from the North or North-West.

3. With regard to the aerodromes in Mesopotamia, they are certainly large, but they are in no way ideal. Most of them are dusty and many of them are covered with small stones. I did not find any real sand aerodromes where the sand was such as to render a machine liable to turn up on its nose. With regard to the stones, the chief trouble is, of course, that they get picked up by the propeller and cause damage, but they also mean excessive wear on tail skids. With regard to dust, this is unpleasant and may cause some difficulties when three or more machines are going off on a flight together, because very often the first one makes such a dust that the remainder cannot get off for some considerable time. This can be avoided to some extent by making all machines taxy down to the end of the aerodrome whence they are going to start off before the first one gets up into the air.

4. The chief troubles I came across may be divided under six headings:—

Timber Shrinkage.
Propellers.
Tyres.
Shock Absorber.
Petrol Supply.
Hangars.

5. With regard to timber shrinkage, I feel that this is a nuisance but not a danger. It is, of course, due to the humidity in the East being different to what it is in England.


PERSIA
PERSIAN GULF
Basrah
TIGRIS
EUPHRATES
MESOPOTAMIA
Baghdad
Ramadie
60 M
400 Miles
ARABIAN DESERT
Kusr-Azrak
Damascus
Amman
55 M
Jerusalem
65 M
Ramleh
260 Miles
DESERT ET TIH
MEDITERRANEAN SEA
Port Said
Heliopolis
Cairo
Alexandria
EGYPT

Timber undoubtedly does shrink when it arrives in Egypt or at Bagdad, but in the former case a definite limit is reached in about two months, after which no further shrinkage occurs, and once the necessary adjustments are made to allow for this, no further difficulties are experienced from this cause.

There must also be a definite limit to the amount of shrinkage in Mesopotamia, otherwise one would have the finest conjuring trick on record, but I have no definite figures as to when this limit is reached.

Certainly in Egypt there is no sign that the timber swells again in the cold weather. As regards Mesopotamia, all I can say is that I could get no evidence to show that any reswelling occurs.

Of course there are various solutions to this shrinkage trouble; *e.g.*, to send out components and build up the machines in the country or to manufacture machines out there from timber that has been locally seasoned, but there is certainly no great difficulty in sending out machines in cases ready assembled. A point to be borne in mind is that metal fittings, especially where they clip completely round a wood member, should be adjustable, and it is also advisable to send out wings in an uncovered condition, because as a rule the planes have to be opened and the fabric stripped off a considerable portion of them in order to tighten up bolts and adjust the fittings generally. From tests that have been made, it does not appear practicable to dry-out timber to tropical humidity in this country and then to build up machines here of this timber. There is difficulty in the drying to begin with, then no varnish can be used that will be vapour proof as distinct from merely waterproof, so that the timber would very quickly get back to the English humidity standard again, and would be no better off.

So long as a machine has to fly merely in Egypt and Mesopotamia there is no necessity to make them all metal, but I still believe that when machines fly constantly from London to Bombay and back it will be necessary to do away with wood in their structure.

I saw one or two cases of laminated spars sent out as spares which had arrived with very ugly cracks in them. It is possible that this may have been due to unequal shrinkage of the two laminæ. Thin three-ply is inclined to blister and to come apart in the laminations. Thicker three-ply stands up fairly well, but causes a certain amount of trouble on a new machine owing to shrinkage.

6. As regards propellers, the wastage of these is high. There are two causes of wastage. First, splitting along the laminations or else actually cracking through the timber of the propeller, generally at the boss.

Secondly, damage to the leading edge of the blade by sand, small stones, or scrub.

The first trouble varies very much with the type of machine. Some of it, I think, has been due to the use of material that has been out in the East a very long time, *i.e.*, three or four years, and it may also be caused by the unequal shrinkage of different laminæ, which naturally must put an enormous strain on the material. I think it may be that the propellers that have given trouble are those with a somewhat low factor of safety, and that when wooden propellers are going to be used in tropical climates it will be necessary to make them somewhat stronger than would be necessary for England.

In some instances new propellers have actually been found to be cracked through the timber or split along the laminations when the box containing them was opened and before they were ever put on a machine.

As regards damage to the leading edge of propellers, the obvious remedy is to cover them with metal, but for use on some aerodromes, such as those round Cairo, very strong metal is required, and thin brass commonly used wears through in from 10 to 15 hours' flying. This metal, by the way, should extend all along the leading edge of the blade and not be limited to the propeller tip.

Metal propellers would afford a complete solution, but I see no reason to suppose that wooden propellers must be condemned for use in tropical climates, and I think a great improvement would be found if propellers were manufactured locally.

7. Tyres must form a large item in the upkeep of machines in tropical climates. There appear to be three sources of trouble: First, deterioration of the rubber of the tyre itself; secondly, deterioration of the valve; thirdly, punctures.

As regards the first, I think again that a good deal of the trouble experienced up to the present has been due to the use of old tyres which have not been stored under the most favourable conditions. There is, however, no doubt that rubber does deteriorate more rapidly in Mesopotamia than it does in England.

As regards valves, I think the solution to this difficulty will be found in the use of an all-metal valve, and we are already carrying out some experiments with this.

As regards punctures, this is due to camel thorn. The thorn that seems to do most of the damage is not very long, perhaps about $\frac{3}{4}$in., but it is very hard and sharp. A tyre seems to have a peculiar fascination for these thorns, and a tyre that has been run over camel thorn feels the same as one's chin does if one hasn't shaved for a couple of days. Some of these numberless thorns get forced through the outer cover and cause a puncture, even though they may not have been originally long enough to have reached the inner tube. I don't think any practicable thickness of rubber will get over this trouble, although it may be noted that D.H.10 tyres, which are 1100 by 220, do not appear to suffer much from the effects of camel thorn, whereas the next size tyre, 900 by 200, does suffer. What one does want is a tyre that is definitely impermeable to camel thorn. Rapson tyres are very successful on the one car that was fitted with them when crossing the desert, but I am afraid the weight of this would be prohibitive. As an instance of tyre trouble, I might remark that when flying over to Bagdad it was necessary to come down on a landing ground that was covered with camel thorn. The Vickers Vimy that was with me punctured one tyre on landing, and this was replaced by a spare wheel carried in the machine. It got off, and on coming down on the next landing ground it was found that three tyres were flat. Having no more spare tyres, the only thing to do was to deflate the fourth one and get off on four flat tyres. This was done successfully, and the machine landed at Bagdad with all four tyres flat. No damage was done to the machine, but the tyres were ruined.

The right solution to my mind is to do away with the need for pneumatic tyres altogether by improvements to undercarriages.

A minor point, but one which probably causes some of the trouble, is flat tyres. There seems rather a tendency in the East not to blow up a tyre too tight because of the belief that the air will expand and burst the tyre when it gets hot. I believe this is a fallacy, but the proper blowing-up of aeroplane tyres is a point to be watched, and to assist this a good form of tyre gauge would be most valuable.

In most cases it has been found desirable to use larger tyres than what was standard during the war; *e.g.*, 800 by 150 instead of 750 by 125 for a D.H.9A.

8. Shock absorbers frequently break in the East. Again, I feel this is largely due to the use of rubber shock absorber that has been in store a very long time or that has been kept under bad conditions. A broken shock absorber may lead to a wrecked aeroplane. One solution is to make use of coiled wire, like the Germans did during the war, in place of rubber. I am told there are difficulties in this, but if the Germans did it, I am quite certain that we can. But what one does want is some form of undercarriage that will do away with the need for rubber shock absorber as well as with the need for pneumatic tyres.

Where rubber shock absorber is used a guard loop of cable should also be put over it, so as to support the weight of the machine if the rubber gives way.

9. An item that may cause an unexpected increase in expenditure of any civilian service in the East is petrol, the wastage of which is apt to be very heavy. I came to the conclusion that the chief cause of wastage is the use of a fragile type of container. The type now in use holds four gallons and is much weaker than the standard two-gallon tin in use in England. Petrol tins are always apt to be handled roughly, and this is especially so with natives in the East. Petrol will ooze through a very minute crack, and although this leakage may be visible in England, it will quite likely pass undetected in a tropical climate, owing to the more rapid rate of evaporation. Again, minute cracks may be caused by internal vapour pressure as well as by rough handling. Also leakage through stoppers will be more rapid than in a temperate climate. It is possible that bulk storage would get over all this, but it would in any case frequently be necessary to use small tins, *i.e.*, up to five or six gallons, and it is very important that these tins shall be of stout construction. The screw stopper should be fitted with a really suitable washer, and it also ought to be covered with a soldered cap. This cap, however, must not be soldered down too firmly, otherwise mechanics are apt to damage the tin in taking it off. It must just be firm enough to be airtight, and that is all.

There is another source of wastage of petrol, though this is not a peculiarity of tropical climates, which occurs when filling up aeroplanes away from an aerodrome. In many machines the petrol tank is very hard to get at, and unless one has a ladder or a pair of steps, the man who is filling up has to get into a very awkward position where he cannot hold the tin steady, with the result that a large proportion splashes over and is wasted and also a considerable amount gets blown away by any wind there may happen to be. I may remark that in the Arabian desert there generally seems to be a wind of about 10 miles an hour on the ground.

Years ago we used to make use of a petrol pourer which would screw into the tin in place of the cap. It really consisted of two tubes, one for letting out the petrol and one for letting in the air. The use of these dropped out during the war. I really don't know why, but I am sure they would be very useful in Mesopotamia. Their use will, of course, necessitate having the tin with a screw stopper and not merely a soldered tin.

10. The upkeep of aeroplane hangars is another very heavy source of expense, mainly for the reason that the canvas covers in Mesopotamia are practically useless after one hot season. Experiments have been tried with regard to placing corrugated iron on the Bessoneau frameworks, and these appear to be quite successful. The chief point to be borne in mind is that no bolts or nails must be driven into the existing framework, otherwise it will not be strong enough to take the corrugated iron. It would appear that the existing frameworks are strong enough except in places exposed to very heavy winds, provided some form of U bolt is used.

11. The fabric on aeroplanes used to cause a considerable amount of trouble owing to rapid deterioration, but I consider this has really been solved by the use of the coloured varnish known as P.C.12 in conjunction with the aluminium varnish known as V.84 on top. The object of the P.C.12, of course, is to prevent the actinic action of the ultra-violet rays on the dope and fabric, while the V.84 reflects the heat rays of the sun and keeps the interior of the planes comparatively cool.

I saw a Bristol Fighter covered with P.C.12 and V.84 which had then flown for 164 hours. The planes were in very good condition, except where the castor oil from the engine had made them rather soggy.

Petrol-resisting tubing of the rubber type, of course, gives trouble in the East, but I don't think much worse than that in England. If the experiments now going on prove that all-metal tubing can be used, then this trouble may also be considered as solved.

The most important point about petrol-resisting tubing is to prevent deterioration in storage by keeping both light and heat away from it. The most effective

means of ensuring this is to store the tubing under water, taking adequate precautions to ensure that the ends of the tubing are kept dry, as otherwise the water will rot the internal canvas plys. One method suggested is to keep the ends of the tubing about 3ins. above the surface of the water and to seal the ends with paraffin wax.

I mentioned previously that tail skids wear very badly on the stony aerodromes of the Middle East. The most effective remedy for this is to fit a detachable rubbing shoe of some hard steel, replacing it as soon as it gets worn through.

Thick triplex glass is bad in the East, as it very soon becomes opaque, but the thin triplex glass as used for goggles does not give trouble of this nature. It is, by the way, very important for pilots to wear tinted goggles, at any rate when flying in the summer, otherwise their eyes are apt to get seriously affected by the sun.

The tail adjusting gear of aeroplanes is liable to suffer damage on account of the dust. The fuselage covering should enclose it completely, and some form of inspection door be provided. On one or two machines holes are left in the fuselage cover to facilitate inspection, such holes ought not to be left open but be fitted with some form of removable cover.

A much-felt want is a good petrol gauge for telling the pilot how much petrol he has left in his tanks. This has been needed as long as I can remember, but very few machines are fitted with one. Sometimes a glass panel is provided in the tank itself, which under favourable conditions can be seen though seldom read by an agile pilot, but what is wanted is some indicator on the instrument board.

Insects in Egypt and Mesopotamia do not attack any part of aeroplanes, but concentrate their efforts on human beings.

12. Now as regards the engines. I could not find any trouble specially due to the climate either in Egypt or Mesopotamia. Of course for most machines an additional radiating surface is necessary; for instance, on the D.H.9A the size of the standard radiator is 6.65 sq. ft., and an auxiliary radiator has to be fitted with an area of 2.5 sq. ft.; on the Bristol Fighter the sizes are, main radiator area 4.1 sq. ft., auxiliary radiator 1.54 sq. ft. With these radiators the water can be kept well below boiling even in the middle of the day.

The most important thing, as most people know, is to prevent the water beginning to boil. Once it has started, it is very difficult to stop. On one occasion I made my pilot take off a machine not fitted with extra radiators at 4 p.m. in the middle of the desert. Both the engines started to boil before we got off the ground, and by the time we got into the air we resembled a locomotive. We had to give it up after about ten minutes, and during that time lost 10 gallons of water out of the 16 in the whole system. Making up 10 gallons is rather a serious problem when you are carrying nothing but drinking water, with the next well 120 miles ahead. During some experiments carried out at Martlesham on this subject, it was found that 72 per cent. of the total water in the system could be lost in three minutes. It is therefore very important to keep a close eye on one's radiator thermometer in the tropics and not to do foolish things, such as leaving one's radiator shutters closed by mistake.

Fitting an auxiliary radiator is much preferable to merely enlarging the size of the standard radiator, because in the cold weather the raditaing surface is too large with the extra radiator, and the latter can then be taken off, thus reducing the head resistance.

Oil radiators have been tried, but have been abandoned as useless and unnecessary. I think it is pretty definite that oil temperatures depend entirely upon the water temperature, and so long as this is kept down there will be no serious trouble with regard to the oil.

Dust appears to give no trouble to engines, except when they are taken down

for overhaul. Great care must be taken that the shop where the engines are being taken down is as dustproof as possible. It is necessary to have double doors, double windows are a great advantage, and in order to allow for closing the windows, some form of forced ventilation is required.

Sparking plugs and magnetos give no particular trouble.

13. There are one or two points about packing. First as regards engines, it seems very hard to prevent these getting rusty on their way out. It is no good, of course, trying to send out engines installed in the fuselage, at any rate in the case of tractor machines, partly because the fuselage is apt to get damaged and also because it is very difficult to get a large case airtight. I believe engines going out to the East ought to be packed in a special dry room, so that the air that is actually enclosed inside the tin-lined and soldered case will not contain any moisture that might cause damage.

One other point. Machines are generally sent out without their wheels, and in some cases shock absorber is wound on the axle and machines sent out with it on. This is a mistake, as the machine is apt to get dragged along on the floor of the packing case, and so the shock absorber gets practically ruined and has to be replaced.

As I mentioned before, I think it is an economy to send out wings in an uncovered state.

14. Perhaps some remarks about the cross-desert route from Cairo to Bagdad may be of some interest. I might say that I had nothing whatever to do with the making of this route, but have merely been over it like a sort of Cook's tourist. The main objects in starting it were first to have the means of supplying Mesopotamia with aeroplanes by air from Egypt, instead of sending them round in cases *via* the Red Sea and the Persian Gulf; secondly, to form the first stage of the air route from Cairo to India and Australia; and thirdly, to establish the means of quick communication between Mesopotamia and Cairo, and so with England. Normally, a letter going from London to Bagdad travels *via* the Suez Canal, the Red Sea, Bombay, Karachi, the Persian Gulf and Basra, and takes between five and six weeks, thus making Mesopotamia, from the point of view of communication, one of the furthest outposts of the Empire. The air route can and is actually altering all this. I have seen in Bagdad a London paper only nine days old. A pilot has arrived in Bagdad $8\frac{1}{2}$ hours after leaving Cairo, and an officer has arrived in London $6\frac{1}{2}$ days after leaving Bagdad.

From very ancient days a caravan route has existed between Damascus and the Euphrates, running practically due east of the former. There is water on this route, whereas to the south of it, where the desert air route now runs, there is practically none. The question then arises, Why fly across the southern part of the desert instead of continuing to follow the caravan route, as has been done on several occasions? The reason for that lies in the fact that under the Peace Treaty the northern boundary of our zone of influence comes a long way south of Damascus and cuts the old caravan route about halfway across. We cannot fly military aeroplanes over other people's zone of influence.

15. With regard to the nature of the country, the word "desert" is somewhat of a misnomer. It is not a sandy desert at all, but rather a steppe, which would probably be very fertile if there were more water. The surface is quite hard, and in many places is covered, or partially covered, with a sort of scrub, which is, of course, all dried up in the summer. It rains, I believe, for about one week in the year, and after that there is a large amount of grazing for camels. The desert lies high, being nearly all over 2,000ft. above the sea, in some places well over 3,000ft. Over a height of about 1,000ft. above the surface there appears to be a permanent westerly wind.

16. The desert is uninhabited as we should understand it, although after the rains a good many nomad Arabs wander over it, grazing their camels. Even

then, as I said before, there is practically no water, except occasional surface water, but the camel food that grows at that period of the year is very succulent, so that the camels do not want to drink. The attendants live on camels' milk. They drink water when they can, but this is reserved chiefly for their women and children. I believe that they sometimes go for as long as two or three months drinking nothing but camels' milk.

Even in the summer there will be an occasional raid across the desert. The object of these is to steal someone else's camels. The raids are generally carried out according to strict rules. For instance, it is very wrong for a raiding party to kill any individual of the tribe whom they are raiding, although the raided tribe may defend themselves. When a man is killed a blood feud is started, but can be cancelled by adequate compensation. The current rate of exchange is 40 camels per man. Again, if the raiders get off with camels belonging to a widow, she can run after them and, using the proper formula, say she is a widow, and demand her camels back. I am told that this is generally done. One of the political officers told me that he was talking to a Sheik and told him that raids were forbidden by the British, and asked why did they still go on doing it, pointing out that Englishmen never raided each other. The Sheik thought for a moment and then said: "Yes, but you play football."

17. The first Air Force party to be sent across this desert was the car convoy. The object of this was partly to select possible landing grounds, but chiefly to make a definite track across the desert which aeroplanes would follow. I have sometimes seen some criticisms of this track, and people say why don't we fly straight across? Well, from the point of view of pure flying this would be the simplest thing to do, and if one did get a few degrees out of one's course one would simply go on until one met the Euphrates; but unfortunately, in this year of grace 1921, one cannot guarantee against engine failure in some form or other. If an aeroplane comes down in the middle of this vast desert it is exceedingly difficult to find, even if it is fitted with wireless, the result being that if there were no form of track we should be bound sooner or later to lose pilots. However, so long as one has got a track, and the aeroplanes follow it, a machine having a forced landing would be bound to be picked up, because even if the wireless did break down, rescue parties would be sent out within 24 hours from each end and they would follow along the track until they saw the damaged machine. Then steps would be taken either to drop water or other supplies, to land in the vicinity or help in some other manner.

Up to June 25th of this year no European, so far as is known, had ever crossed this part of the desert from east to west, or vice versa. People have, of course, been along the caravan route to the north, and others, such as Miss Gertrude Bell, Mosil and Colonel Leachman, had wandered over a large part of the desert, but mainly in a direction of north and south. It was, therefore, somewhat of a bold conception to decide to send off a small party to cross this unknown desert. The fact that it was accomplished successfully, I think, reflects great credit on those responsible for its initiation and organisation, as well as the actual performers. The car party had many difficulties to contend with, especially during the first part, where a passage through lava had to be found. Final success was due chiefly to effective co-operation between aeroplanes and the cars, the former reconnoitring the route and bringing out supplies from Amman. On the outward journey six Crossley light tenders and three Rolls-Royce cars belonging to the Machine Gun Corps, were taken; all bar one vehicle have now done the complete journey to Bagdad and back.

18. A great many experiments were carried out as to the best method of marking the route, but it was eventually found that the wheel tracks of the cars themselves were sufficient in most places, each vehicle following closely in the tracks of the preceding ones. Over certain portions of the route it was necessary to use a sort of wide shallow plough, and this was also used to make arrows by the

side of the track occasionally. I don't suppose a car track of this nature would be of much value in a sandy desert, but it is certainly most effective between Amman and the Euphrates, and there is no real difficulty in following it from the air. One has to use one's brain a little bit, *i.e.*, sometimes one has to look two or three miles ahead and sometimes one has to look almost vertically downwards. From the pilot's point of view there is a great advantage in having a continuous line of this nature to follow, instead of occasional marks such as bomb craters, and it is rather fascinating to watch the little narrow line stretching away in the distance, the one thread linking you not only to civilisation but to food and water.

19. Before this car party started the maps of that part of the world observed a discreet blankness, but now the route followed by the cars and some of the prominent points near it have been accurately fixed by surveyors. They made use of the stars for fixing their position at night accurately and this method entails knowing the exact time. The chief surveyor took a small wireless set with him and every night about half-past ten used to set it up and listen for the time signals from the Eiffel Tower, and this checked his chronometer to a tenth of a second. There is something rather romantic about this, the operator in the centre of a great city working his sending key and, all unknown to himself, enabling some stranger over 2,000 miles away to locate his position in a trackless desert.

20. Now as regards the journey itself. I won't say anything about the part from Cairo to Amman because many people know that part of the world. However, here is a slide (not printed) showing the officers' mess at one of our aerodromes, not far from Jerusalem, consisting, you see, chiefly of aeroplane cases. This is just to show that the Air Force are not spending a large amount of the public's money on permanent buildings, but endeavouring to be economical. The Dead Sea looks quite pretty from the air and quite reminded me of the Italian lakes; but the Jordan, at any rate in the summer, is disappointing, being a miserable, dirty little ripple, in fact I quite sympathised with Naaman in not wishing to bathe in it.

Amman is a town with about 12,000 inhabitants, including a great many Circassians who were originally sent there by the Turks to keep control over the Arabs. In old days it used to be the headquarters of a Roman legion. There are still remains of a Roman amphitheatre and of one or two temples, and when you go down to a bazaar in Amman you will probably find yourself on a stone which, when examined, is seen to be the capitol or base of a Roman filler. Amman is at present the capital of Trans-Jordania, and Abdul, king of that part of the world, has his court in a big camp at Amman. The aerodrome here is very dusty, about 2,700 feet above the sea, and has higher ground around. It is an unpleasant aerodrome to get off from in a slow-climbing machine.

The first point out from Amman is Azrak. There is no village or anything there but water springs, which form a series of pools in the summer and a lake in the winter. The ground immediately round these pools is fertile and the place forms rather a centre for nomads. The Romans had a fort here, the foundations of which are still to be seen, and the Persians built a castle, the ruins of which are still left. The water is beautifully clear and quite good to drink.

From Amman to Azrak the country is undulating and bare, in fact one may say the desert begins a few miles east of Amman. At Azrak one begins to get into the first part of the lava country. There are masses of this lava about, but so far as is known there is no volcano. The lava appears to have welled up out of the earth through a sort of crevasse and merely flooded over the whole countryside. The Persian castle and the old Roman fort I referred to are built of lava.

From Azrak onwards one also comes across what are called mud flats. These are large areas of a sort of light yellow soil which looks white and almost dazzling in the sun. They are perfectly level and smooth, nothing grows on them, and some of them are several square miles in extent. In many ways they form an absolutely ideal aerodrome, the only drawback being that they are so smooth and

level that it is very difficult to judge one's height; in fact it is like alighting on a perfectly smooth sea. The best plan is to come down quite low over the edge and land just beyond it. The surface is quite hard, and though it is cut into by tail skids, is but little affected by aeroplane wheels. These mud flats are probably formed of the matter which is carried down in suspension by streams during the rains. It seems probable that they are covered with water during the rainy season; in fact one or two were still wet in July.

I spent a night on one of these mud flats owing to the fact that one of three machines in my flight had to land on account of engine trouble.

This formed another instance of the value of wireless in the desert. The machine that had engine trouble sent out a wireless message to say it would be forced to land. That was taken down in my machine and the message handed to me and at the same time it was being received at Bagdad and Amman, and from the last transmitted to Cairo. So in a few minutes there was I up in the middle of the air over the desert, Bagdad and Cairo, all knowing that this particular machine was having to land and why.

After a bit of fairly open steppe country one then comes to the second lava outcrop about 120 miles from Amman. The lava here is much more continuous than it is close to Azrak, and it was here that the car convoy met with their greatest difficulties. It is a most depressing area of country to fly over, and it has quite a bad effect upon one's nerves, at any rate some people's. I know I felt as if the end of the world had really come and there was no one left alive except my pilot and myself, and that the sooner we joined the rest the better. The lava ends just before landing ground F, and from there practically till one reaches the Euphrates, the country is open steppe. A peculiar thing about this lava country is that there are traces of some ancient civilisation on it. There are several circles of lava blocks which may very likely be the remains of houses, but in addition there are straight walls, which from the air look like the boundaries between fields, in fact they are not unike an open stone wall country in England, such as that round Cirencester. I noticed these walls principally on the eastern edge of the lava.

El Djid is a sort of half way place between Amman and Bagdad, and one constantly sees it referred to. It is marked on many maps; in fact some people think that there is a large village, and even a town there. This slide (not printed) shows what El Djid really consists of—simply a well. There are actually two wells there, one of them about 160ft. deep bored through solid limestone; who made it I don't know. The water tastes very good.

21. On the occasion that I crossed the desert to Bagdad there was quite a gathering at El Djid. There was the R.A.F. car convoy returning from the east, another car convoy, which had been reconnoitring for a railway, came down from the north, and my flight of three aeroplanes from the west, three independent parties all meeting at this poor little well in the midst of the vast uncharted desert. On this particular occasion the party that came down from the north told me that they had come across a Sheik who had been wounded two days before in the course of a raid made on him, and suggested that, as this Sheik had been friendly to the R.A.F. convoy at the time it was moving to Bagdad, it would be a good thing to fly him to Bagdad for hospital treatment. This was referred by wireless to Sir Percy Cox in Bagdad, who agreed, and so we decided to do it. A couple of Ford cars were sent off to pick up the Sheik and take him to the landing ground known as L.G.4A. About four hours later I started off with three machines, and just as we got over L.G.4A we saw two little black dots hurrying along over the desert, these being the two Ford cars with the wounded Sheik and a friend of his. We landed all right, put the Sheik into one of our machines, the Vickers-Vimy, and eventually got him to Bagdad in safety. What the Sheik thought of it I do not know; poor man, he was not given much of a chance to

object. Hustled first into a Ford car, then out of that into this strange-looking contraption of wood and canvas, borne for hundreds of miles through the air, lifted into an ambulance, and before he knew what was actually occurring he was lying on a bed in Bagdad hospital and being X-rayed. Somewhat alarming for a wild sort of child of nature, who had probably never slept in a house in his life. There was a rather interesting sequel to this; a few days later one of our machines landing at El Djid to fill up with petrol was damaged. A flight of six more machines were sent out from Bagdad to take out spares and mechanics to repair it, and the whole party had to spend the night at El Djid. Just about sunset they saw five men on camels ride up and proceed to take up an outpost line round them. These five men remained thus on guard all through the night, and at dawn mounted their camels and rode silently away. It was found later that these were five men from our wounded Sheik's tribe who, learning that the Air Force were in some trouble, had taken steps to ensure that they were not molested during the night. The Sheik has recovered and is now back with his tribe.

There appears to be a sort of natural fellow-feeling between these nomad Arabs and the Air Force. Perhaps both feel that they are at times in conflict with the vast elemental forces of nature, forces which could completely overwhelm them at any moment, were it not for the fact that nature is on the whole tolerant to such puny little creatures as human beings. I came across a case of the same sort of friendly feeling occurring in the Sinai Desert.

22. In the country between the Euphrates and the Tigris there are traces of the old civilisation, chiefly in the way of canals, which are now dry. Nearly all the existing cultivation in that area lies close by the banks of the two rivers, and between them is practically a desert. So far as I can make out there is not much point in building canals at present in this part of the world, because if one did put more land under cultivation there is no labour to work it. One cannot import labour partly because the climate is unsuitable and partly because the Arabs won't have it, so if one wants to make Mesopotamia prosperous the only thing to do is to reduce the infantile mortality, which I believe at present amounts to as much as 70 per cent.

Bagdad is a disappointing place, at any rate approaching it from the air, being simply a glorified mud village and hardly distinguishable at evening from the desert.

23. As regards the equipment to be carried by machines in the desert, there are certain things that are essential:—First, a supply of water and food for every individual. At present the military machines carry five gallons of water and ten days' rations per head. The rations by the way want to be suitable for the desert; bully beef and Army biscuits are not very appetising; but things like dates, tinned fish, if it hasn't gone bad, and some form of thin biscuit, are what is wanted, specially dates. Then as regards the machines. Always take at least one spare wheel, some Very's lights, smoke flares for dropping from the machine to give wind direction on the ground, signalling strips for making signals to a rescue party in case one has trouble, picketing gear for the machine, propeller covers, a few small tools and weapons of some sort. A small medical companion is also desirable, and this should consist not merely of bandages, but contain a few of those medicines that one does want in the East, *e.g.*, permanganate of potash for water, phenacetin and chlorodyne. Picketing gear is most important in the desert because you never know when a sudden gust will not come up, and they are sometimes so violent as to upset a Handley Page. It ought to be a recognised routine that before anything else, when a machine is landed in the desert, the machine must be properly pegged down.

24. It is very important that a machine crossing this desert should be able to fly the whole way across, or at any rate between Ramadi and Amman, without

having to fill up with petrol. At present, although a D.H.9A can fly from Amman to Bagdad, it cannot fly from Bagdad to Amman without refilling. This is of course on account of the permanent westerly wind. This means carrying petrol in tins, usually slung on under the lower planes, and then landing to fill the tank. Now a landing in the desert is apt to lead to trouble, largely on account of the vagaries of the wind. As a case in point, when Sir G. Salmond and I were flying back from Bagdad, we landed at El Djid to fill up with petrol. The first of the three machines to land damaged its undercarriage, not badly, but it couldn't get off as it stood. We decided to leave it there and proceed with the other two, after sending a wireless message to Bagdad to say what had occurred. Six machines had to be sent from Bagdad to bring out a spare undercarriage, tools, trestle, etc., and one of these six also damaged itself, in fact a good deal worse than the first machine. Well, if any attempt had been made to rescue that second machine I suppose 12 aeroplanes would have had to come out, and then two of those 12 would have crashed. However, the Officer Commanding Mesopotamia wisely decided to cut his losses, and made no attempt to get back the second damaged machine. To soothe our economists I might add that the engine and instruments were salved.

25. Now as regards the prospects of this desert route for civilian enterprise. My own opinion, which is probably quite valueless, is that it is not suitable for civilian traffic at the present time.

A journey across that desert is in the nature of a military operation. There is always a good sporting chance of trouble with somebody, of Arab raiders, and the first thing one does if one has to spend the night in the desert is to get one's machine-gun ready. However, once the whole country has settled down, I feel confident that there will be great openings for civil air services, and those interested cannot begin to study the subject too early. It was with the object of assisting this, that I ventured to give this so-called lecture to-day.

TABLE I.

MEAN DAILY MAX. AND MIN. TEMPERATURES.

Month.	Cairo.		Alexandria.	
	Max.	Min.	Max.	Min.
January ...	77	36	73	44
February ...	79	39	75	43
March... ...	84	43	81	48
April	99	47	94	52
May	103	54	98	58
June	104	62	96	65
July	101	65	91	69
August ...	99	67	90	71
September ...	97	61	94	66
October ...	93	57	93	58
November ...	84	46	83	53
December ...	74	41	75	47

TABLE II.

NORMAL RELATIVE HUMIDITY AT LONDON, CAIRO (HELWAN).

		Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
London	07.00 hrs.	87	85	86	84	81	80	81	85	89	91	90	87	85.5
	13.00 ,,	80	75	68	62	61	60	59	61	65	73	79	82	68.79
	18.00 ,,	84	80	74	66	63	62	61	65	73	83	86	86	73.58
Cairo (Helwan)	07.00 hrs.	69	64	63	55	50	55	65	69	68	67	68	70	63.58
	13.00 ,,	42	34	29	23	20	21	24	27	30	33	37	44	30.3
	18.00 ,,	56	48	43	36	32	33	34	40	48	51	54	58	44.4

These figures for Helwan Aerodrome would be 10-20% higher, as these records are taken at Helwan Observatory on the hill, 115 metres high.

TABLE III.

AVERAGES AND EXTREMES AT BAGDAD, 1888-1918.

Lat. 33 21′ N. Long. 44 × 26′ E.

Month.	Mean.	Temperature. Mean Monthly Extremes. Max.	Min.	Absolute Extremes. Max.	Min.	Relative Humidity at 8 a.m.	Rainfall. Amount.	Days.
January ...	46.8	67.7	29.3	79.9	20.8	78	1.13	4.7
February ...	53.0	73.6	32.4	84.8	27.7	73	1.10	4.1
March ...	60.3	83.7	40.0	98.8	33.5	69	1.23	5.1
April ...	70.2	92.7	50.1	107.7	43.8	60	0.82	2.8
May ...	80.7	103.8	58.1	112.6	46.5	50	0.20	1.2
June ...	89.6	112.3	69.0	119.2	62.8	37	0.00	0.1
July ...	94.0	116.0	73.1	122.8	69.6	37	0.00	0
August ...	93.8	116.7	72.3	121.0	68.9	40	0.02	0.1
September ...	86.9	112.0	63.4	117.2	56.0	42	0.00	0.1
October ...	76.3	101.8	54.1	108.0	47.5	51	0.08	0.7
November ...	60.7	86.0	40.2	95.3	29.5	66	0.84	3.1
December ...	50.3	71.5	33.0	81.0	18.6	79	1.22	4.7
Year ...	71.9	94.8	51.4	122.8	18.6	57	6.64	27

TABLE IV.

TEMPERATURES INSIDE DIFFERENT BUILDINGS AT BAGDAD, 21st JULY, 1921.

Time.	Men's Quarters.	Permanent Hangar.	Bessonneau Hangar.	Workshop with very high roof.
0600	87	82	84	90
0800	93	93	96	95
1000	102	105	110	103
1200	103	110	121	107
1400	106	120	125	109
1600	108	123	124	110
1800	108	117	115	108

Maximum temperature inside an aeroplane case containing new machine ... 130°.
Maximum shade temperature in the open ... ... 116°.

DISCUSSION.

Mr. F. Handley Page said they had heard an exceedingly interesting lecture, and it was also interesting to see all those pictures of a land which to most of them was entirely unknown and to realise the enormous number of different kinds of people who in different times of the world's history had crossed over the same parts of the world. Take Xenophon and the Ten Thousand marching over similar ground. What a different experience they would have had if the journey had been carried out as General Brooke-Popham had carried it out. One might also imagine Solomon flying over there and speculating on the way of an eagle (Mark VIII. Rolls) in the air.

More particularly from the point of view of the aircraft constructor, one wondered whether it would be a necessity that metal machines should be employed on those routes. He was not altogether convinced that their use would come very quickly. When one had wood spare parts could easily be carried or made on the spot, and wood had so much greater local strength than steel. If one had steel an enormous supply of spare parts must be carried to repair the wings with the special kind of material that was necessary for aircraft. So he was not altogether convinced yet that they had completely done away with wood for these big tropical temperatures. He would like to know from the Lecturer whether he thought it was an absolute necessity. When he (Mr. Handley Page) was over in the States this year he examined metal machines which had been in operation under service conditions on the postal service. There was first of all trouble with petrol tanks leaking. The petrol tanks being in the planes, the leakage caused gas to accumulate, with the result that the planes were blown off with the inevitable explosion that occurred after an engine back-fire. They had also had trouble with the metal covering of the planes corroding and being eaten away by electrolytic action, especially where those parts were heavily stressed. That simple little trouble seemed to be a considerable one from the point of view of keeping the machines in condition for flying. He would like to lay emphasis on that side of the question as being one which must not be overlooked when they were thinking of substituting metal for wood in very hot climates.

He would like to remark how exceedingly apposite it was to have a discussion on aeroplanes for tropical climates at the present time when we had a temperature of 84 degrees in the shade. They should all devote attention to the probable climate of this country next year, and if it were to be as hot as that of the season now ending those interested in the London and Paris service would do well to winter in Mesopotamia, so as to be ready for the coming season between London and Paris.

Brigadier-General CADDELL said that the romantic side appealed far more strongly to him than any other.

To have crossed in one day the four great rivers of history—the Nile, the Jordan, the Euphrates and the Tigris—was a most wonderful feat.

Looking back to the times when the famous cities of Nineveh, Babylon, were in existence, it was in 2000 B.C. that Sennacherib, whose name was made immortal by Byron, crossed the Tigris, Euphrates and Jordan, but his armies of 200,000 men were smitten by the Angel of the Lord on the borders of Egypt before he could reach the Nile.

Seventeen hundred years later Alexander crossed all four rivers, and if there were only a witch or wizard of Endor present who could raise him up, his experiences would be interesting to hear.

Dealing with the technical side, the speaker inquired if, in view of the success of the 90 h.p. R.A.F. engine in Egypt, steps could not be taken to develop a good air-cooled engine for use on the Cairo-Bagdad route.

From the commercial point of view the running of such a service was a difficult problem, though he felt it was capable of solution.

One of the main disadvantages was the supply of personel, as the white man would require high wages and would probably want a great deal of leave in such climates. The speaker asked if any developments had taken place in the scheme originated about May, 1918, by Vice-Marshal Sir Geoffrey Salmond for the instruction of the young Egyptian in technical matters.

As the Cairo-Bagdad service would soon be in regular operation the speaker suggested that commercial aviation would be materially assisted if the R.A.F. machines on this route were permitted to carry, up to a specified load, ordinary business letters.

Colonel W. D. BEATTY said that the Lecturer had brought out a very large number of points which were well worthy of attention by firms operating routes in these latitudes, as well as by those who contemplated operating in the Middle East.

Taking tyres, for instance, these give a good deal of trouble in England. During the war the Germans *had* to cut down their use as much as possible, though he must say that the samples of solid-tyred wheels which he had seen did not give him the impression that they had seriously tackled the problem. Why should we not try a pressed steel wheel with a steel tyre, arranging for all the shock-absorbing capacity to be provided in the oleo gear?

He felt sure that both constructors and users of aircraft would like to know the latest information regarding the very promising flexible metal joints—details of the design of which have recently been published. He believed he had seen figures somewhere showing that the majority of forced landings can be traced back to defects in the rubber connections at present used in the petrol system.

The trouble with Triplex glass, mentioned by the Lecturer, has been experienced in England during this last summer on motor cars.

He would like to emphasise the need, mentioned by the Lecturer, for a really good petrol gauge. Could not the designers of water and gas meters produce a meter which, calibrated during manufacture, and including a distant reading

gauge, could be fitted to any tank? It might be so arranged that the tank was both filled and emptied through the meter, and the pilot would know exactly what fuel he had at any moment.

In regard to oil temperature, is it really clear that oil radiators are not required? If his recollection were correct, the experience of the Martinsyde in the last Gordon-Bennett race pointed to the necessity for an oil cooler under certain conditions. He believed that the trouble with this machine was due to lack of oil pressure, the oil reaching and maintaining a state of boiling, and so remaining mainly foam, although the water temperature was reasonably low.

If any information had yet been compiled on the matter, it would be interesting to know whether the conditions experienced in practice at aerodromes situated at a considerable altitude are the same as might be foretold by calculation. For instance, did the run required to get off at Amman correspond with the calculated run based on the performance of the machine at sea level?

The question of prevailing winds is one which, as the Lecturer has shown, has an important bearing on the design of machines to be used on a given route, and it is a matter which is very liable to be overlooked when the operation of a new route is being considered.

The general impression he had received from this most interesting lecture was that new troubles need not be anticipated in operating routes in the countries in question, but that those troubles known in England will be met with in exaggerated forms.

At a forced landing in England, for instance, the local inhabitants may steal a watch, or provide a car for the pilot's convenience, while in Mesopotamia they may carry the idea so far as to steal the pilot's life, or provide him with a packet of dates to save him from starvation!

Major-General Sir W. Brancker: I don't quite agree with Air Commodore Brooke-Popham's remark that the Cairo to Bagdad route is unsuited for a commercial transport service at present. After all, the existence of pirates and privateers in the past was never used as a reason to confine seagoing activities to ships of war!

It is all very well to say that these services will be handed over to commercial control when the right time comes; human nature is strong, and no one likes the idea of reducing establishment, so that Government may cling to the control of the service for many years and thereby prevent progress on one of the most important air routes in the British Empire. There are certain Government aviation officials now whom the outside world consider useless, but who are longing to find something to "control" and so justify their existence.

We have seen sufficient of Government control in the past to justify a most earnest prayer that it will not be permitted to exert its baneful influence on aerial transport in the future.

Colonel H. T. Tizard said he had an impression that the troubles to which the Lecturer called attention remained troubles longer than they need because the makers in this country did not hear of them to the extent which they might. For example, a good deal had been heard of the rubber troubles in the tropics, but nothing very definite. It was known that rubber deteriorated quickly there, but the causes still seemed to be uncertain. Until more definite information existed it was difficult to get improvement on the part of the industry. A great deal of good might be done by really reasoned technical reports from the big users of such materials in the tropics. If reports were only received from small users, they might concern isolated cases, and hence might possibly be misleading.

In reference to the water trouble with engines, he thought it was quite possible to use oil for cooling. An oil could be used which would circulate well at a temperature of 150 deg., which would be a long way below its flash-point.

The cylinder wall temperature of an air-cooled engine was a great deal higher than 150 deg. The use of oil would increase the efficiency of the radiator and prevent troubles to which the Lecturer referred. It should be possible to use an oil that boiled at 250 deg. and could be used satisfactorily in the cooling system of an engine at about 120 to 150 deg.; if so, there would be no sign of trouble due to boiling. The question was worth taking up more energetically.

One remark of the Lecturer's which the audience appreciated very much was that in regard to the assistance of wireless to men in the desert and to the general operations of aeroplanes out in the East. Wireless telegraphy was almost a supreme example of what could develop from the work of a few enthusiasts in a laboratory. In these days of urgent need for economy, it is well to remember the importance of pure research which to the sternly practical man may seem to be useless at the time.

Major-General Sir R. M. Ruck thanked the Lecturer very much for his excellent lecture, and he thought the Secretary should also be congratulated on his brilliant inspiration when, in the absence of anyone else, he told off the Chairman to give his lecture this afternoon. It had given them a lot of very interesting information which they could not have got in any other way. He would also like, on behalf of the members, to congratulate the Lecturer on the delightful manner in which he had presented the subject. Air Commodore Brooke-Popham was an old member of the Society and had been a very good friend to it both as a member and Chairman, and also in a high official capacity. He moved that he be accorded a very hearty vote of thanks.

In reply to a question by the Lecturer, Squadron Leader Hill said the Bristol Fighter had flown between 100 and 200 hours with all-metal petrol joints.

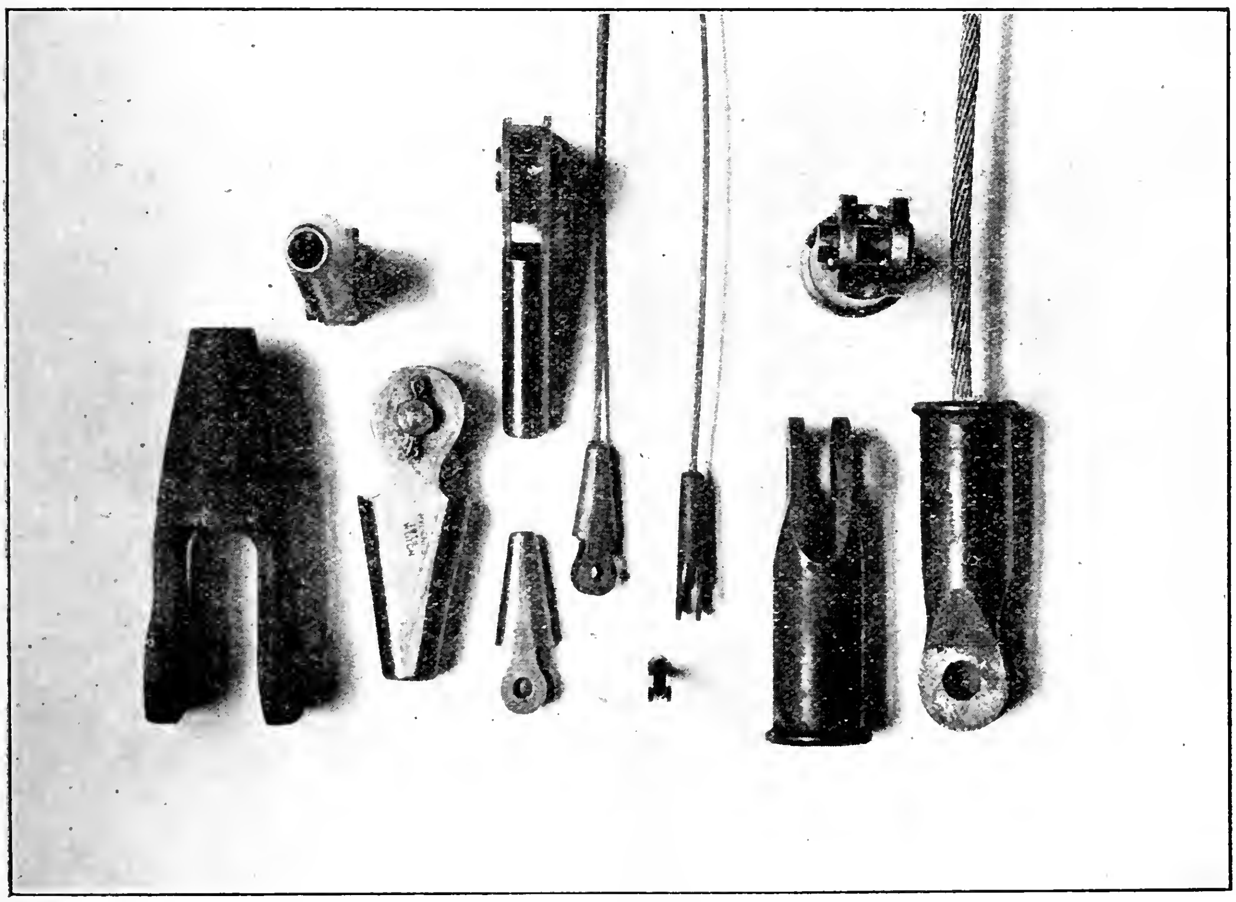
The Lecturer said they were doing a good deal of work with regard to air-cooled engines, although practically all the engines out in the Middle East now were water-cooled. There were advantages in the air-cooled engines, but they must be as reliable as the water-cooled before they could be put into service. The possibility, however, of having 10 gallons of one's drinking water boiled away in 10 minutes was a serious one. As regarded Egyptian mechanics, they had been taken on to some extent, and many of them were extraordinarily good, especially mechanics in repair shops and on M.T. Also many Maltese carpenters had been taken on, and they were also very good. He was afraid he could not express any opinion with regard to commercial letters at present.

The Lecturer said he had stated in the Lecture that he did not think it necessary to have metal machines if they were going to operate in a tropical climate only, but he felt if one were going to fly from England through Bagdad to Bombay and back with the same machine one would have trouble with wood. Wood machines were all right if one stuck to a route between Cairo and Bombay.

SOCKETS FOR WIRE CABLES.

BY WALTER A. SCOBLE.

An earlier article* dealt with so many matters in connection with wire cables that it was possible to pay but scant attention to sockets. A socket is a neat, light and convenient form of end connection for a cable. It is widely employed in general practice, but its use in connection with aircraft appears to have been confined to airships. The photograph shows different types and sizes of sockets viewed in several directions.



That on the extreme left is made of low tensile steel and is an example of the usual commercial type. Three of each of these types of airship sockets are included to give three views so that the form can be clearly seen. The sample on the extreme right is unnecessarily heavy. Those seen in the centre of the photograph are best for aircraft. They are very light and taper in one direction only so that they have small wind resistance. The top forms a pin joint.

To form this type of end connection the cable is passed through the circular end of the socket. The opening is just large enough to take the seized cable. The wires are allowed to open out and separate in the tapered socket, and a hard solder is poured in which adheres to the wires, but not to the socket, and so forms a wedge. When the cable is put under tension the wedge of solder draws slightly down the socket and closes on the wires.

* "Wire Cables." Aeronautical Journal, October, 1920.

The socket should not be too large; it must be fairly well filled by the cable, or the cable may draw out by shearing the solder. On the other hand, if the socket is too small, particularly if the cable is composed of a large number of wires, there is not sufficient room to allow the metal to run down and form a good wedge. These points are mentioned here, but are not likely to give trouble in practice. A socket which just takes a cable is generally satisfactory, but if a 7×37 wire cable is used, it can be made to enter a standard socket which is too small to take the large number of wires.

The table is included to indicate the dimensions of a range of sockets which have given satisfactory service on airships. They were made of steel to Specification S.2 by Cradock and Rylands.

Cable strength.	Length, end of socket to pin centre. ins.	Width. ins.	Maximum breadth. ins.	Wall thickness. ins.	Pin diameter. ins.	Weight. (including pin and pulley). lb.
25 cwt. ...	$1\frac{9}{16}$	$\frac{5}{16}$	$\frac{9}{16}$	$\frac{1}{16}$	$\frac{3}{16}$	.047
2 tons ...	$1\frac{15}{16}$	$\frac{13}{32}$	$\frac{11}{16}$	$\frac{3}{32}$	$\frac{1}{4}$	.098
3 ,, ...	$2\frac{5}{8}$	$\frac{1}{2}$	$\frac{15}{16}$	$\frac{3}{32}$	$\frac{5}{16}$	—
4 ,, ...	$3\frac{1}{4}$	$\frac{9}{16}$	$1\frac{3}{16}$	$\frac{3}{32}$	$\frac{3}{8}$	.247
8 ,, ...	$3\frac{1}{4}$	$\frac{3}{4}$	$1\frac{7}{16}$	$\frac{3}{16}$	$\frac{7}{16}$	.483

The coated wire used for aircraft cable is very suitable for socketing, and a satisfactory job can be made by a semi-skilled workman if the cable is composed of several strands. Single strand does not always present sufficient surface to be held by the metal up to the breaking point.

The following instructions were drawn up for the procedure during socketing.

The end of the cable will be bound. Note the place on the cable which will come at the end of the socket and put on a binding in this position. This serving may be of binding wire, but for smaller ropes tarred twine is to be preferred. It holds the cable together when the end serving is removed to spread the wires. The length of this serving should be from $\frac{1}{4}$in. for 15cwt. cable to $\frac{1}{2}$in. for 7-ton rope.

Thread the cable into the socket. Take off the end binding and spread the wires.

Bind the cable with asbestos cord for a short distance from the end of the socket to protect it from heat.

Heat the socket gently at the eye end until it can just be touched by the finger and thumb at the other end. Be extremely careful not to overheat the cable where it leaves the socket.

Put powdered resin into the hot socket and pour in melted solder (Tinman's).

Clear out any excess solder to allow sufficient clearance below the pin.

These instructions were prepared because it was found that in certain cases the wire was overheated at the small end of the socket and that failure consequently occurred there. Even when failure occurred as a result of overheating, the strength was not greatly below that of the original wire as the table shows.

Nominal strength of cable, cwt.	15	20	25	35
Load when fractured at socket, cwt.	15.2 to 19.4	19.0 to 22.1	22.1 to 26.3	29.5 to 37.
Average, ditto, ditto ...	17.4 (11)	20.4 (6)	24.1 (20)	32.9

It should be noticed that these results refer to fractures at the socket which occurred during routine testing, when the socketing was done under service conditions and no special precautions were taken. Even then the results were not very bad, because clear breaks, which allowed the full strength of the cable to be developed, were the general rule and the socket breaks were exceptional.

After the instructions were issued it was found that failures were extremely rare and the damage could be detected by the discoloration of the wire. In all other cases of the many hundred samples that were tested, the wire failed well clear of the sockets.

This type of end fitting was found to be the only practical way of testing samples of K.B. wire. K.B. wires are of specially high tensile steel 150-160 tons/in., and very thorough research into the failure of these wires under shock and vibration was conducted. For these tests the taper socket was the end connection and gave completely satisfactory results, as it developed the full strength even of this specially high tensile wire under the severe treatment.

Several hundred samples of kite balloon cables (7.1 tons) were socketed at each end for testing. This method proved entirely satisfactory, but for these larger ropes Babbitt metal No. 1 replaced solder, and the sockets were not heated. Heating the socket allows the metal to run in better, but if the wire of the cable is annealed where it leaves the socket, its strength is reduced. Dewrances' alloy No. 232 was even better for socketing, but Babbitt No. 1 was preferred because it is a standard alloy.

In connection with the point raised that the socket must be large enough to allow the metal to run well down, a case occurred when the cables broke in the sockets, in one case at a tension of 6.36 tons, and the best result which could be obtained was a strength of 7.6 tons. Circular sockets were available and were bored out to $\frac{1}{16}$in. and $\frac{1}{8}$in. larger diameter. In each case the eye of the socket was broken at from 8.7 to 9.1 tons tension.

It is hoped that this brief account will suffice to present the advantages of this type of end connection. When no special precautions were taken, the results were good, but if a few simple rules are observed, the full strength of a cable is always developed.

In conclusion, the essential features are repeated :—

Use hard solder for small sockets and a harder metal, such as Babbitt No. 1, for large cables.

The socket must be large enough to allow the metal to run through.

The socket should not be heated, but if it is small for the cable and heat is applied, protect the cable where it leaves the socket.

STANDARDISED STABILITY TERMS.*

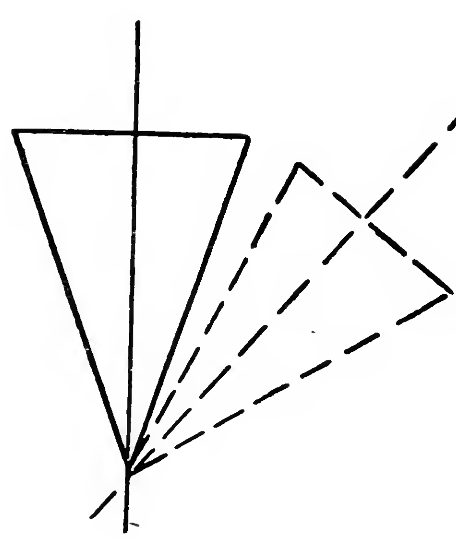
1. *Introductory.*—In the course of inquiries made recently by the Accidents Investigation Sub-Committee they were impressed by the fact that the various terms normally used to describe the characteristics of an aeroplane in regard to its stability or instability are incomplete and defective from a pilot's point of view. Not only did there appear to be differences in the meanings attached to the various stability terms by pilots and others, but in several cases the meanings were not in accordance with the definitions used in physical science generally.

It appeared that a scheme of definitions could be drawn up which would be acceptable both to those interested practically and theoretically in the subject. Definitions are needed for discussions on stability and particularly in making more definite the information given by pilots when describing the behaviour of aeroplanes. It is felt that the definitions, if accepted on all hands, would lead to such observations during the life of an aeroplane as materially to assist the investigations of accidents. In arriving at agreement on the definitions which follow, the Sub-Committee have been fortunate in having the assistance of representatives of each of the branches of the subject.

2. *Stability and Instability.*—The term "stability" is not confined in its uses to aeronautics. There are standard works by Routh, Kelvin and others relating to the motion of both solids and fluids. It seems to be very desirable that, so far as possible, aeronautical applications should conform with older usage.

If one considers a body—such as a cone at rest on its apex—with the point of support exactly below the centre of gravity, the general definition of its condition is that of *unstable equilibrium.* There is no tendency for the body to fall one way or another until a disturbance occurs; a disturbance having occurred, the body falls over and does not tend to recover its initial position, but takes up a position of stable or neutral equilibrium when laid on the ground.

Had the point of support been above the centre of gravity as in a conical pendulum, the effect of a disturbance would have been to produce an oscillation about the mean position. At rest, the pendulum is in *stable equilibrium.*



If one considers the body to be released when in the dotted position it is unprofitable to speak of its stability, since it is not in equilibrium and will fall

* Aeronautical Research Committee Reports and Memoranda, No. 745. June, 1921.

without any accidental disturbance. Mathematically, one only considers the stability of a position of equilibrium or the permanence of a state of steady motion.

Balance.—The expression which is partly in use, and is recommended for the purposes of defining the condition of an aeroplane in a state of steady motion, is that it is in " balance."*

In longitudinal motion, if there be no force on the control column, so that the attitude of the aeroplane is not changed by the removal of the pilot's hand, then the aeroplane is commonly said to be in longitudinal balance. For example, whether the adjustable tail plane be locked mechanically or the elevator be locked by being firmly held, it is in either case legitimate to speak of the aeroplane as in balance.

A less common use of the word carries the above idea forward from longitudinal to lateral motion, and it is recommended that " balance " should correspond with the idea of steady motion generally, the qualifying adjectives " longitudinal " and " lateral " being used for the purpose of restriction.

It would appear to be a logical extension of existing usage if the word " balance " be applied also to any steady motion of an aeroplane for which the controls are held or locked.

Steady Motion.—When the motion of an aeroplane is steady, its attitude, its airspeed, its rate of turn and its angle of bank do not change from instant to instant.

3. In applying these ideas, it is desirable to avoid the expression " stable aeroplane."† For example :—

(*a*) The straight line motion of an aeroplane may be stable or unstable.
(*b*) The circling flight of an aeroplane may be stable or unstable.
(*c*) The spinning nose dive of an aeroplane may be stable or unstable.
(*d*) There is no point in speaking of the stability of a loop or roll. During these manœuvres the aeroplane is changing its attitude and speed, and is therefore not in a steady motion.

4. Ideas are complicated by the consideration of similar manœuvres with certain controls locked or free. If an aeroplane be flown with controls used so that its path is steady and the rudder bar be then abandoned, the motion will almost certainly change. This should not be described as instability, since it follows from the fact that the rudder changes its position when the rudder bar is released. It is to be regarded as an effect of movement of control and is analogous to the change of longitudinal motion which accompanies use of the elevator.

With this introduction one would say :—

(*e*) A given type of steady motion is *stable* if the aeroplane will continue in that state of motion without movement of the controls by the pilot.

(*f*) A given type of steady motion is *unstable* if the aeroplane will not continue in that state of motion without movement of the controls by the pilot.

5. Explanations of terms relating to stability are given below.

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* " Trim " has in the past sometimes been used as synonymous with " balance." It is recommended that the word " trim " be reserved for a " rigging " operation.

† The definition of a stable aeroplane as one which, whatever be done to it, the aeroplane comes back to straight flight on releasing or centralising the controls, is to be discouraged, since it is far less useful than the new proposal when it is desired to refer to the various qualities or behaviour of an aeroplane for variations of flight conditions.

Stability and Instability of a Weathercock.—If the conventional type of wind vane points into the wind, it is said to possess weathercock stability. This effect is obtained by putting a large fin area behind the supporting spindle. If the vane does not keep into the wind when set there, but blows round to some position away from the wind, the condition is one of weathercock instability.

Weathercock Stability and Instability of the straight line motion of an Aeroplane.—The aeroplane is presumed to be controlled by the pilot so as to be flying straight with the wings horizontal. At some instant of time the *rudder bar is locked.* A disturbance occurs and the ailerons are used to keep an even keel. If the aeroplane becomes yawed, *i.e.,* is sideslipping either to right or left and to increase the amount (indicated by the cross level of the aeroplane), the straight line motion exhibits weathercock instability. If, on the other hand, the aeroplane continues to fly straight, the motion has weathercock stability.

In still air the test for weathercock stability would be given by a kick to the rudder bar with immediate return to its previous position. Before the kick the aeroplane is flying straight with wings horizontal, and during the further motion the ailerons are used to maintain an even keel. Weathercock stability exists if there is return to a straight path, though in a new direction.*

The weathercock stability and instability of the circling flight of an aeroplane can be determined by analogous considerations.

Rolling Stability† *of the straight line motion of an Aeroplane.*—The aeroplane is presumed to be controlled by the pilot so as to be flying straight with the wings horizontal. At some instant of time the *ailerons are locked,* but the rudder is still used to keep a straight path. If, whenever one wing goes down due to a "bump," and tends to return to the horizontal, the motion is stable. If, on the other hand, the wing tends to go down further, the motion shows "rolling instability." The motion is not pure rolling,‡ but is accompanied by sideslipping.

In still air, the test for rolling instability would be given by a jerk on the ailerons sufficient to depress one wing. If, after subsequent return of the control column, the aeroplane tends to resume an even keel, there is "rolling stability."

It is useful to extend the definitions of rolling stability to cover the case in which ailerons are abandoned. Qualifying notes are then needed in applying the definitions, and these may be "rolling stability ailerons locked" and "rolling stability ailerons free."

Rolling Stability of Circling Flight.—If an aeroplane can be kept on a given turn in bumpy weather by means of rudder and elevator only its circling flight has rolling stability, or, alternatively, if the aeroplane on such a turn tends to correct a change in angle of bank due to a gust without the use of ailerons, its circling flight has "rolling stability."

Lateral Stability of the Straight Line Motion of an Aeroplane.—The aeroplane is presumed to be in straight flight with the pilot in control. At a chosen instant *both ailerons and rudder are locked.* The elevator is used only to maintain steady speed and attitude. If the aeroplane continues in straight flight the motion has complete *lateral* stability. The motion of an aeroplane may have both "weathercock" and "rolling" stability and yet not have complete lateral stability. Departure from the straight path may occur (*a*) by weathercock instability, (*b*) by an increasing oscillation in roll and yaw, or (*c*) by the starting of a turn which becomes overbanked. The second of these (*b*) is described as an

* When an even keel is maintained by means of the aileron and a constant angle of incidence by the elevator, the effect is to preclude any rotation except about the vertical axis.

† This has sometimes been described as "lateral stability," a term the true meaning of which is given below. It is recommended that such use be discontinued, as the term has another and more important use dealt with elsewhere.

‡ The motion has no connection with the "aerobatic manœuvre" called a "roll."

unstable lateral oscillation; the last (*c*) presents greater difficulties, and has hitherto been called "spiral instability." The name now suggested is "yaw-roll instability." An aeroplane having the defect (*c*) tends to start an increasing turn with increasing bank, thereby taking up a converging spiral path.

Lateral Stability of Circling Flight.—If before locking the ailerons and rudder the flight is one of steady turn, corresponding definitions will hold. Modifications may also be desired for ailerons free, but rudder locked.

It is strongly recommended that the term "lateral stability" be restricted to those cases when the motion is completely stable. This conforms with the use in physical science. Any motion which involves rolling, yawing and side-slipping in any relation whatever is included in lateral motions. It is because the term "lateral stability" is generic and inclusive that it must not be used for a particular case, such as "rolling" stability.

6. Perhaps an illustration of the use of ideas in relation to spinning may help to emphasise the need for the definitions given to balance and stability.

Spinning.—An aeroplane is flying steadily and horizontally at a given instant at an angle of incidence below stalling. The design of the aeroplane is assumed to be such that the pilot has been able to adjust the controls so that, when locked, the aeroplane continues to fly itself straight at, say, 90 m.p.h.

(*a*) We then conclude that the straight line motion of the aeroplane at 90 m.p.h. is longitudinally and laterally stable with all controls locked.

At a given instant the stick is pulled back and the engine is throttled down.

(*b*) The aeroplane is now out of balance—longitudinally by change of engine power and movement of elevator, laterally by the change of slipstream over the fin and rudder. Considerations of longitudinal stability are excluded by this lack of balance.

It will be assumed that the rudder is used to maintain lateral balance* until the aeroplane is stalled while being on an even keel, and it is then possible to consider the stability of the lateral motion when the longitudinal changes have overstalled the aeroplane.

(*c*) The lateral motion of the aeroplane becomes unstable and one wing drops, the aeroplane puts its nose down and rotates. After a little time the spinning nose dive is fully developed.

(*d*) Whilst the stick is held back the spinning continues and the motion is stable (minor effects of rudder are ignored).

The stick is put forward and the rudder centralised.

(*e*) The spinning nose dive becomes unstable laterally and the spin tops, leaving the aeroplane in a dive, *i.e.*, out of balance longitudinally.

(*f*) The stick, rudder and engine throttle are brought back to the positions at the beginning of the manœuvre and the aeroplane resumes its steady horizontal flight at 90 m.p.h., this being by hypothesis the stable condition for the pre-supposed position of the controls.

(Signed) MERVYN O'GORMAN,
Chairman, Accidents Sub-Committee.

* This is probably a departure from usual practice, but is a possible motion.

ORGANISATION OF A COLONIAL AIRSHIP SERVICE.

Lecture delivered before the Royal Aeronautical Society, Scottish Branch, on October 17th, 1921.

BY LIEUT.-COL. V. C. RICHMOND, O.B.E., B.SC., A.R.C.S., ASSOCIATE FELLOW.

(1) Introduction.

I feel it a great honour to have been asked by this Society to speak to you this evening on this subject. The question of the utilisation of airships for commercial purposes has attracted an immense amount of public attention during the past year. Unfortunately, owing to the high costs of running airships experimentally, the Air Ministry have been faced during this period with the necessity of having to abandon airships for military purposes, and also of having to cease their experiments on the use of these ships for commercial purposes. Fortunately it is inherent in the British temperament to give its greatest sympathy to a man when he is down, and for this reason, concurrently with the complete cessation of all airship activities, such stupendous ideas as the use of airships for linking up the Colonies have been put forward. The scheme for using aircraft on such an unprecedented scale for commercial purposes is so gigantic as to call for very grave and careful consideration.

Ever since the armistice airship pioneers and experts have been giving the problem their attention, and it has been entered into in far greater detail than ever the public imagine probably. Since I received your Secretary's invitation to lecture to you we have been faced with the tragic disaster to R.38, with the loss of all those courageous and brilliant men who, as I say, have been giving this problem their most earnest consideration for the past three years.

A good deal has been written in the Press on this subject, but I feel it all the greater honour that the task should have been allotted to me of presenting to you this summary of the project which these men had so closely at heart.

Let me say at the outset that my acknowledgments and best thanks are due to Air Commodore Brooke-Popham, Director of Research, for permission to give this lecture, and also to Major G. H. Scott and other officers of the C.G.C.A. and Directorate Research Departments of the Air Ministry for their kind assistance in the preparation of some of the matter. I need hardly add that any views I may express must not necessarily be taken as the official views of the Air Ministry.

I shall have occasion later to refer briefly to the comparative value of aeroplanes and airships for commercial communication with the Colonies, but you are probably familiar with the contention that the airship is peculiarly suited for long distance voyages over the sea, or for routes which necessitate at present mixed land and sea journeys with all their attendant inconveniences. You will readily appreciate that in this respect the British Empire is unique, possessing a large number of such routes with a well established flow of passengers and goods only waiting to be increased by more rapid means of transport. I would draw your attention to the fact that the committee, recently set up by the Dominion Premiers to advise them on aerial communications, did not question in any way the ability of airships to carry out the services which experts claim for them, and therefore the soundest and most profitable ground for development of commercial airship transport is the British Empire. I will go further and say that it is absolutely essential, with such a scattered empire as ours, that we should be foremost in

this development, as rapidity of communication is the most vital of all military and economic influences.

It will not be out of place, perhaps, if at this point I digress for a moment to give a brief account of the airship activities of other countries at the present time, as far as we know them.

(2) Airship Activities of other Countries.

(a) America.

The United States of America are taking a very vital interest indeed in the question of airship construction, both for commercial and military purposes. The largest airship shed in the world has been erected by them at Lakehurst, New Jersey, the shed being capable of accommodating one airship of ten million cubic feet capacity, or two airships of five million cubic feet capacity each. Sheds are being erected at Cape May and Langley Field slightly larger than the largest existing sheds in England, capable of housing airships of up to four million cubic feet capacity. The erection of a base on the Pacific coast is also contemplated. The Americans are considering the question of design and construction very thoroughly indeed, and are at present engaged on the construction of a rigid airship similar to the German L.49 type. Most of the prominent German airship constructors have visited America and there is every evidence that in some cases their services have been bespoken. It is also well known that the Americans are trying to acquire from the Zeppelin Company an airship whose performance should far exceed that of any of the ships which have so far been produced. A company, termed the "General Air Service Company," is being formed for the purpose of operating commercial airships on trans-continental and trans-oceanic routes. It has very good backing from several of the large commercial corporations, and it is likely to begin extensive operations in the near future.

Perhaps one of the most striking facts with regard to the American interest in airships is the large amount of money which has been spent on a plant erected at Fort Worth in Texas for the production of helium. Helium is an absolutely non-inflammable and inert gas with a 96 per cent. lift of pure hydrogen. You will see that it would be ideal, therefore, for use in airships, and the Americans are singularly fortunate in possessing large supplies of natural gas which contain a comparatively large percentage of helium. Even so, the work of extracting the helium is an expensive one. The plant cost approximately $3\frac{1}{4}$ million dollars and produces 40,000 cubic feet of helium per day. I understand that the United States have placed an embargo on the export of helium, which shows how important they regard the matter.

(b) France.

France possesses three German airships, handed over under the terms of the Peace Treaty—including L.72, which was one of the two largest airships built prior to R.38, and also the "Nordstern," the latest German commercial airship built since the Armistice. A large shed has just been completed near Toulon, and a second shed is under construction. At Maubeuge there is a shed constructed by the Germans during the war, and seven of the German airship sheds allocated to France under the terms of the Peace Treaty are being dismantled with a view to their re-erection in France and her colonies.

It is understood that the "Nordstern" is to be used on a commercial service between Marseilles and Algiers. The Algerian Assembly have approved the inscription in the 1922 budget of a credit of one million francs for the purpose of subsidising certain aerial services between Paris, Marseilles and Algiers, part of which is to be carried out with the "Nordstern." Such a service would complete the first link in a route to South America in which, it is understood, the French have considerable interest.

(c) **Germany.**

The Germans are precluded at present from building aircraft until three months after the satisfactory completion of all their obligations under the aerial clauses of the Treaty of Versailles. It is probable that they will be free in this respect by about next spring. The Zeppelin Company have been keeping their works going on motor cars and various other commercial articles with the object of being able to re-commence airship building at the earliest possible moment.

One of the long distance routes which they favour most is that from Spain to South America, and you will probably all have read in the Press that the arrangements for this route are pretty well advanced.

(3) Historical Parallel.

It is inevitable that many nations of the world will make every effort to derive the maximum benefit from this wonderful new instrument of transport as soon as may be. I can think of no parallel in history where any scientific development—which has reached the stage of advancement which airships have reached—has ever stood still. It has been said recently that "the airship is just as certain of being guided by energy and patience to achieve the end in view as Stevenson's 'Rocket' was of covering England with railway lines." Unfortunately, it is just as certain that it is experiencing, and will experience for some time to come, the same amount of prejudice as the "Rocket," the first steamship, the first motor car, and in fact the ordinary push bicycle had to contend with in their early days.

In reading the history of the development of shipping from early days I have been struck by the number of very close parallels it provides to the state of affairs through which the airships have passed and are passing now. I may perhaps be excused for pointing out some of these to you on the plea that pushing the analogy still further we may gain wise guidance for the future. Little more than a century ago the shipping of the world was engaged almost solely in carrying luxuries for the wealthy and in some cases transporting the more adventurous of them on voyages of business and pleasure. I suppose this represents with a fair degree of truth the kind of traffic with which the airship will endeavour to commence earning money. These islands by their geographical position were designed by nature to be the home of a great shipping community, just as I have said that the British Empire has the most advantageous routes in the world for the utilisation of airship transport. One sees that the old wooden sailing ships reached their prime in 1870 and that people could not imagine anything faster or finer than those racing clippers. Their names were as familiar as those of any football team are to-day, and their races home were followed with the keenest interest. But iron ships came, which it was proved could be built stronger for the same weight. The prejudice against them was colossal. Indeed the Chief Constructor of one of the Royal Dockyards said to Mr. Scott Russel, years after the success of iron for shipbuilding had been fully demonstrated: "Don't talk to me about ships of iron, it's contrary to nature." It is quite easy to make a mental flight over a few decades and hear the wiseacres saying: "Fifty tons of metal floating in the air—God never intended people to travel about like that—it's contrary to nature." The invention of the rolling mill by Henry Cort revolutionised the building of iron ships. Useful plates, channels and angles could be produced and unsatisfactory cast iron boilers could be given up. One's mind instinctively flies to the history of rigid airship building. First of all aluminium was used by Zeppelin—an unworkable metal with most unsatisfactory mechanical properties for the purpose. His rivals, the Schutte-Lanz Co., were quick to see the advantages of wood, which successfully held the field until Zeppelin countered this with the introduction of the famous duralumin alloy, which could be rolled and pressed into channels, etc. The introduction of steam into shipping was the signal for more mountains of prejudice. There were scientists who attempted to prove that

it would be an utter impossibility to steam across the Atlantic, the ships could not possibly carry enough coal, etc. "Foul steam kettles," said others, "they will all burst their boilers and you will be drowned." Can you not hear the man of to-day saying, "By the time the airship has got its fuel and ballast on board there is not sufficient lift left to make it worth running commercially; besides, hydrogen is so inflammable, the ships are bound to blow up." In 1825 a subscription of £8,000 was raised in India for a prize for the first steamship voyage from England. Later a prize of £500 was offered for the fastest steam passage to Australia. Special ships were built which eventually won these prizes, but which themselves were of very little use for commerce, although of course improved shipbuilding was stimulated. How like the great aeronautical competitions of to-day! In 1838 comparatively large subsidies were offered by the Admiralty (which was then responsible for the foreign mail service) for the carriage of the North American mails by steamship. This was not until their prejudice had been swept away by public opinion, which saw clearly that the steamship ensured both greater speed and greater regularity. The tender which was accepted led to the formation of the Cunard Co., which was extremely successful. The Americans, who were jealous of this success, offered a larger subsidy, which in turn had to be countered by a still larger subsidy to the Cunard Co. The parallel to the events of our time is perhaps too obvious for me to draw it here. Similarly, with regard to size. Who amongst the early steamship builders could have imagined a ship the size of the "Aquitania"? When only doubling the size of the early ships was mooted people said "it was madness, they would be too fragile, they could never stand a rough sea." Yet the "Aquitania" is at least six times as long as the early steamships. Similarly, with regard to airships. There seems no inherent reason why they should not be built in the future of very greatly increased capacity—rugged steel ships with metal plating for a cover. People did not refrain from building large steamships because of the cost of building larger docks, nor can I imagine them refraining from building large airships because of the shed costs. In any case the mooring mast, which is a comparatively cheap affair, will perform the equivalent functions of a wet dock, and the shed those of the dry dock or building slips.

Who calls the "Aquitania" a "foul steam kettle" now? Yet I have read the remarks of the chairman of the Imperial Shipping Committee on airships (I shall have occasion to refer to them again later), and it seems that speed, that great god of commerce, has marked down even the "Aquitania." Our fathers may not live to see the funeral, but the signs are unmistakable. Who is to foot the coal bill when the airships carry the mails and the millionaires?

(4) The Comparative Value of Airships and Aeroplanes for an Imperial Air Service.

On the second of their terms of reference, viz., "On Services by means of Aeroplanes," the Imperial Air Communications Committee observe what appears to be a profound reticence. My own view on this matter is that the functions of the airship and the aeroplane respectively are truly complementary and do not overlap. For distances which are small compared with a normal long distance airship flight of, say, 2,000 miles, the aeroplane does, of course, possess definite advantages especially over land in its superior speed. There is no doubt that if sufficient bases were laid down with sufficient relays of aeroplanes a fairly regular service could be established by this means to the Colonies, but what the capital cost and annual expenditure of such a service would be I should not like to attempt to predict. I shall have occasion later to refer to the present volume of traffic between this country and the Colonies, both in passengers and mails. Even presuming that such a large proportion as half of this could be sent by air, I venture to think that, at any rate for the present, this volume of traffic would

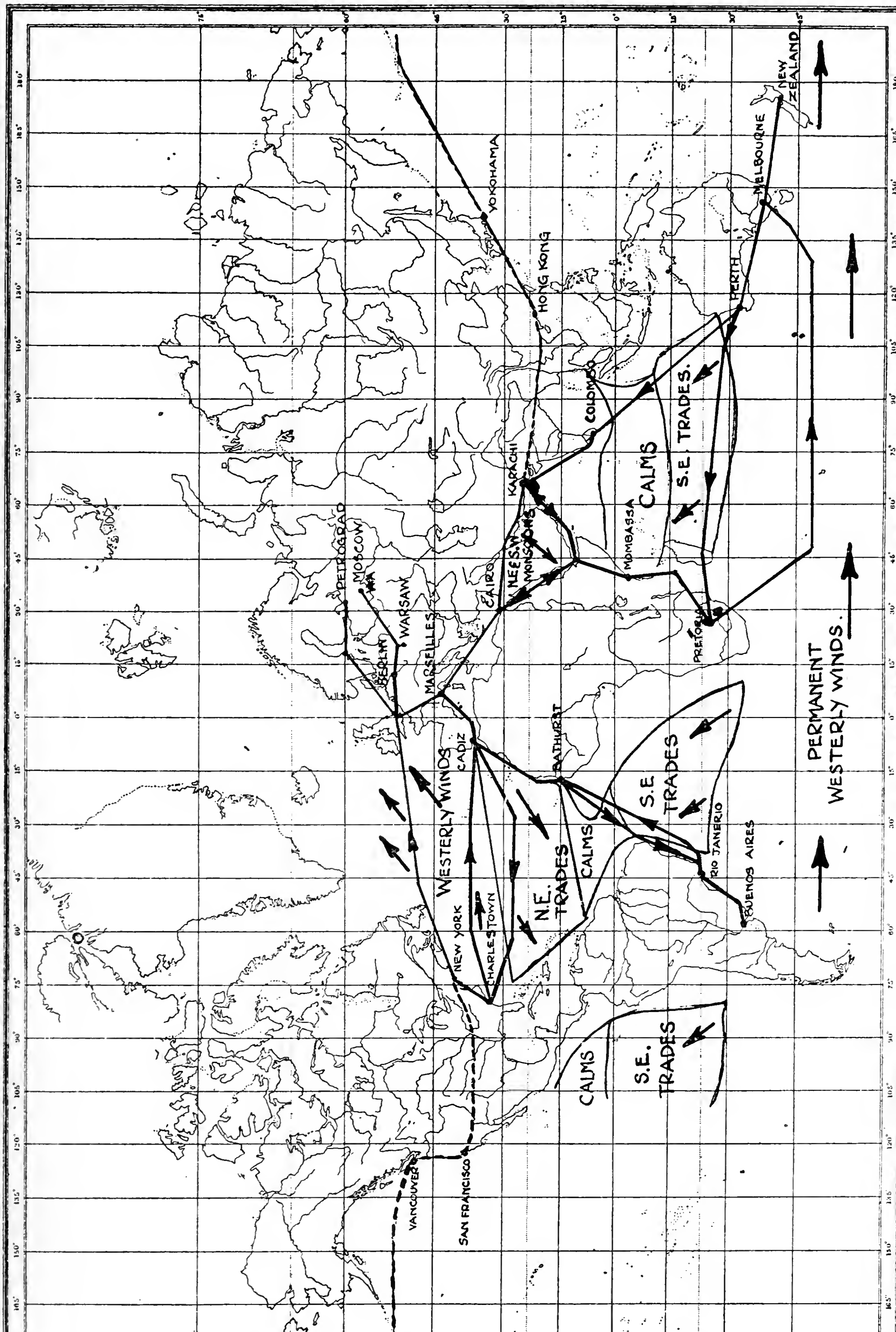
not be sufficient to justify the large capital costs of the many aeroplane landing grounds, etc., which would be required along the route. Also, it will be obvious to you that, although the actual air speed of the aeroplane would be considerably higher than that of the airship, the extra number of stops which would be required on a run of, say, 2,000 miles, would reduce the effective speed of the aeroplane very considerably.

The meteorological organisation of a service of this kind will have to be very good, and full advantage will have to be taken of prevalent winds. You will understand that the shorter the distance between the stopping places the less the opportunity of avoiding dangerous winds or meteorological conditions or of taking full advantage of the favourable ones. In this respect the airship on its long-distance non-stop run would have very definite advantages over the aeroplane. Fog and low-lying clouds are a distinct danger to the aeroplane, and as the frequent stopping places bind it to a pretty definite route, serious delays in the regularity of the service might be caused by such clouds or fogs, even although these might only occupy a limited portion of the route.

Generally speaking, the air speed of the aeroplane is about twice that of the airship and for short routes where a steady head wind may be encountered of 30 or 40 m.p.h. the speed of the aeroplane over the ground is more than twice that of the airship, while its regularity of flight is considerably greater. For this reason the aeroplane undoubtedly holds the field. Over short routes very great speed is essential. The route must be chosen with care, however, because in some cases even the high speed aeroplane will not possess the commercial advantages which might appear at first sight. Take for example the internal communications of Great Britain. If a business man in London wishes to go to Glasgow, Cardiff, Newcastle, or any of the other great business centres he can leave his office to-day at the usual time, take a comfortable dinner, proceed in a luxurious sleeping coach on the railway, have a comfortable breakfast at the other end and reach his business associate's office at the beginning of the day without undue mental or physical fatigue. Even if the aeroplane could fly with safety at night, which it cannot at present, the gain to the business man in flying from London to any one or other of the great industrial centres in two or three hours is almost negligible. The same thing applies to mail. If the business man can despatch his letter at the end of one day and his associate receive it the next morning, all ordinary requirements are satisfied. Any more urgent requirement is likely to be met much more effectively by a good telephone system than by rapid aeroplane transport.

The question of mental and physical comfort in travel is a vital one. Presuming that the present type of aeroplane were used on these long distance routes, I very much doubt if more than eight to ten hours flying per day would be accomplished. In order to effect a reasonably rapid journey this ten hours per day would have to be kept up for every day throughout the flight. The amount of transhipment and the anxiety of the continual landings would, in my opinion, make ten hours flying by aeroplane per day every day quite unsupportable by the average business man.

I should like to repeat, however, that I consider the functions of these two classes of aircraft are distinctly complementary. When communication between one large centre in each colony has been established by airship, the aeroplane will assume a very definite and important roll in distributing passengers and mail, and freight from that centre to the various parts of the colony with the minimum loss of time. It would be very galling for instance if having made the journey by airship from England to India in, say, five days, one was then obliged to spend two days in a train to reach some destination, say 800 miles from the landing terminal.



YOKOHAMA
HONG KONG
NEW ZEALAND
MELBOURNE
PERTH
COLOMBO
KARACHI
S.E. TRADES.
CALMS
MOMBASSA
N.E.-S.W. MONSOONS
CAIRO
PETROGRAD
MOSCOW
WARSAW
BERLIN
MARSEILLES
PRETORIA
PERMANENT WESTERLY WINDS.
CADIZ
BATHURST
WESTERLY WINDS
S.E TRADES
CALMS
N.E. TRADES
RIO JANERIO
BUENOS AIRES
NEW YORK
CHARLESTOWN
S.E. TRADES
CALMS
VANCOUVER
SAN FRANCISCO

(5) General Organisation.

You may have noticed that, although the Committee on the Imperial Air Communications have devoted the bulk of their report to estimates of the cost of running a State airship service, they make the following significant remarks in their preface :—

"The Committee take the opportunity of observing that in their view the best hope of the successful development of Imperial Air Communications lies in private enterprise conducting the service for profit, like the Mercantile Marine, on business lines."

There is no doubt that airship communication with the colonies can only make healthy development on such lines. It is obvious that the organisation must pass through an experimental development period of probably three or four years before it can reach the stable conditions of regular freight and passenger traffic, such as I have laid down later in the section dealing with financial organisation. It would, however, be quite unsound to legislate for this period of experiment only, owing to the fact that the bases, mooring masts, ships, etc., which would be required must be so laid down and designed as to be suitable for continuous commercial traffic at the end of the experimental period, because of the high costs involved. For this reason I am inclined to regard the existing airships as being of not very great utility and, in fact, of much less value than has commonly been placed on them. I feel, however, that a certain amount of useful information would be obtained and the public would learn to gain more confidence in the utility of the airship if the existing ships were run on some comparatively short route which did not involve any great capital expenditure. A route such as Cardington to Marseilles would be ideal in this respect as there would be terminal facilities at each end and the only capital outlay would be for the repair and re-commissioning of two of the existing ships, a comparatively small matter. Incidentally it would link up with the proposed French service to Algiers. From the experience which the Germans gained in running the "Bodensee" between Lake Constance and Berlin there seems no reason to doubt that sufficient passengers and freight could be found for the "Marseilles-Bedford" route and that with a subsidy of the order of 25 per cent. of the gross takings, such as is at present paid to the Cross-Channel aeroplanes, the service could be run without loss. I feel that any attempt to use the existing airships for longer routes than this would definitely be a mistake. Some information might be obtained, but it must be remembered that these ships were all built for war purposes and many improvements have been effected since they were designed four years ago. It would be folly, therefore, to make the case for the airship stand or fall on the performance of these craft in a service for which they were never designed or intended.

It may be gathered from the Imperial Air Communications Committee's report that, generally speaking, the capital expenditure which will be required to finally establish a weekly service both ways to each of the Colonies, India, South Africa and Australia, would be in the region of four million pounds. Such a service would take about four to five years to establish. It is obvious that any commercial undertaking during that five years would require very considerable Government assistance to enable them to carry out their project. From a study of the various proposals which have been made to the Air Ministry, it will be seen that the general opinion is that the subsidy required would be in the region of £300,000 per annum and that, with the guarantee which this subsidy would bring, the capital sum of four million pounds required could be raised. Seeing the scale of the project which is to be undertaken it does not seem unreasonable to suppose that this sum could be found between the Dominions and the Mother Country. You will probably have noticed from the Press that Mr. Hughes, the Prime Minister of Australia, is to place before his Parliament a scheme for airship development involving a grant by Australia of £250,000 to cover two

years' work. Unfortunately, the details of his proposals are not yet to hand, but if this money is actually granted by the Australian Parliament and sums commensurate with it are granted by the Parliaments of the other Dominions and this country, the assistance should be sufficient to enable the Imperial Airship scheme to go forward on healthy lines. As far as this country is concerned, a grant of £660,000 has been made to cover three years for a mere Cross-Channel aeroplane service. Also about 45 million pounds have been spent already on the airships, and therefore a subsidy of, say, £200,000 per annum by the Home Government, would not appear an unreasonable amount to ensure that the great benefits which would arise from an Imperial Airship Service should be secured as a return for this huge expenditure. It seems pretty clear also that any such sums set aside by the various Parliaments would be far better spent as a subsidy to a commercial undertaking than on a State service, because with the subsidy as guarantee of interest the commercial concern could secure the benefits of large capital.

Under such an arrangement it is suggested that the State's rights in the commercial airship company should be as follows:—

(1) First call on the available accommodation for the conduct of imperial business.

(2) Absolute control of the fleet in time of war.

(3) Facilities, if necessary, for training Government personnel on the airships in time of peace.

(4) Full use of the company's aerodromes and facilities for military aeroplanes on terms to be agreed.

(5) The Air Ministry to have a seat on the Board of Directors.

As I shall suggest later on in considering the question of revenue, the company should carry an amount of mail equal to approximately half the present mail traffic to the colonies specified, at a cost of 6d. per oz. to India and South Africa and 9d. per oz. to Australia. The definite co-operation of the Government would be necessary to this end.

It will be noticed that in their considerations the Imperial Air Communications Committee have dealt solely with the Colonies of India, South Africa and Australia. It is natural that an Imperial Airship Service should develop first in this direction. The first part of the route as far as Egypt is common to all three services, and also these Colonies would have most to gain from such a service. Therefore, in what follows I have confined my attention almost exclusively to these three colonies.

The reason why airship communication is not likely to develop with Canada until much later is that the whole of the journey would be over the sea, where, of course, no intermediate stopping places can be arranged and the distance between the terminals would be about 3,000 miles, whereas with the type of ship contemplated for the service to the East, a 2,000-mile journey is about the economic maximum. It must also be remembered that comparatively high speed luxurious steamship travel has been provided across the North Atlantic, and there is plenty of traffic in that class of passenger who can easily pay sufficiently high prices to make it worth while running such a costly steamship service. It is, therefore, unlikely that the service to Canada will develop until considerably larger and faster ships are built than we have any experience of at present.

One of the points to be carefully studied in the organisation of any airship service is the avoidance of dangerous weather conditions and the necessity of taking full advantage of favourable winds. There are practically no favourable winds for passage westwards across the North Atlantic, and probably head winds will be encountered all the way. The speed made good over the area in which head wind is experienced is the difference between the speed of the airship in still

air and the speed of the wind. I should like to give you the following simple example to show how important a small increase in the speed of the airship becomes under these conditions. A ship of 50 knots speed proceeding against a wind of 40 knots only makes good ten knots, and if the area of the head wind is 100 miles, the time taken would be ten hours, during which the ship would have flown 500 air miles, so that 400 air miles are wasted. Now imagine that the ship is so constructed as to be capable of an independent speed of 60 knots, *i.e.*, an increase of one-fifth of the speed previously considered. Her ground speed would then be 20 knots under the conditions stated above, and the time taken over the area of head wind would be five hours and the air miles flown would be 300, thus only 200 air miles are wasted as against 400 in the previous case. I am quoting Major Scott when I say that it is considered that an airship with a speed of 70 knots could carry out a regular service across the North Atlantic at any time of the year.

(6) Technical Organisation.

(*a*) Ground Organisation.

In the attached map you will see indicated roughly the proposed routes, together with a general indication of the various winds which would be experienced over these routes. It is natural that the position of bases and mooring masts are to a certain extent governed by geographical conditions. At the same time there are economic factors to be considered governing the best distance apart for these calling places, and these I will now briefly indicate.

Annual costs may be divided into two parts:—

(*a*) The cost of upkeep of bases and ships, plus the cost of insurance, staff, etc., not including gas and petrol. (This may be termed the terminal cost.)

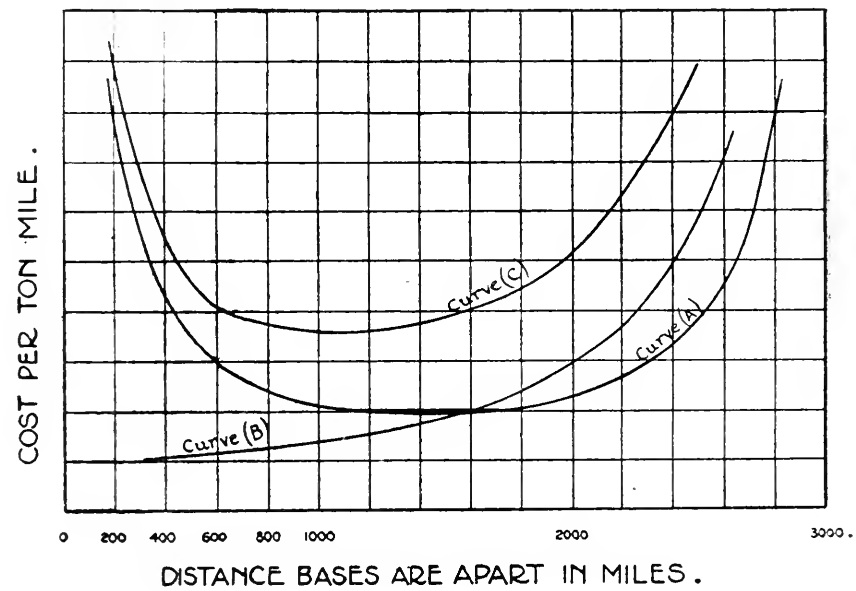
(*b*) Running cost of airships. This includes the cost of petrol and gas.

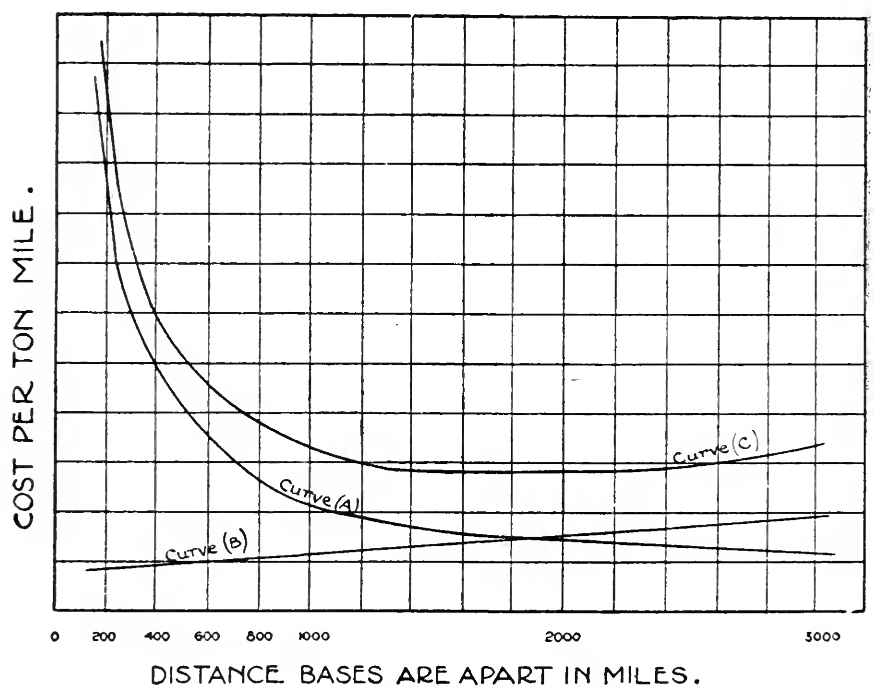
You will readily understand that whatever distance the bases are apart the costs under (*a*) will remain the same, so that the terminal cost per ton mile decreases as the distance apart of the bases is increased, but the weight of petrol carried increases with the distance to be flown, so that the available lift for cargo decreases with the distance. The terminal cost per ton mile should, therefore, be divided by the weight of freight carried to give a factor connecting terminal costs with the distance between successive terminals. I have indicated this in curve A on Chart I.

The running cost per mile remains the same, however far the bases are apart, but as before, the weight of freight decreases with the length of the journey, so that the running cost per ton mile increases with the distance apart of the bases. This is shown in curve B. If we combine these two curves we get curve C, the lowest point of which indicates the most economical distance apart for successive bases. The introduction of an intermediate mooring mast modifies the situation considerably as terminal costs for this are small; chart 2 shows this. These curves are only meant to be diagrammatic and hence only approximately represent an actual case. Bearing in mind these considerations, and those applying to geographical conditions and prevalent winds, the attached map shows the positions which are contemplated for bases and mooring masts. These are as follows:—

England—for the present Cardington (Bedford), where the mast which has been dismantled from Croydon would be re-erected with an additional mast. The existing airship shed would have to be lengthened and, in order to deal with the construction and repair work which will be required when the service which I am outlining has been established, two additional airship sheds will also be necessary.

Near Marseilles the French have a large airship station where it is hoped a mast will be erected which would serve as an intermediate stopping place on the first long run to Cairo. At Cairo a base would have to be constructed which will consist of a shed at present owned by the British Government, part of which is erected and part of which is still lying at the maker's works, a mooring mast, hydrogen plant and all the other etceteras required by a base. As far as Cairo the route would be common to the three colonial services contemplated. Taking





first the Indian route, it is considered that this could be successfully operated from the Cairo base with merely a mooring mast station at Karachi. For the South African route, a new base with mooring mast would be required near Durban, and an intermediate mooring mast, say at Mombasa. The route to Australia might be operated either via the African base or via India, but there seems little doubt that the former alternative is the better one to choose owing to the prevalent winds. In sailing eastward from Durban to Melbourne in

TIME TABLE FOR AUSTRALIAN SERVICE VIA SOUTH AFRICA.

FIVE AIRSHIPS REQUIRED LETTERED A, B, C, D AND E RESPECTIVELY.

Day.		England. Arrival.	England. Depart.	South Africa. Arrival.	South Africa. Depart.	Australia. Arrival.	Australia. Depart.	
Mon.	1st week.		A	E			D	
Tues.					E			
Wed.								
Thur.				D				7 days' flying.
Fri.		C			D	E		
Sat.								
Sun.								
Mon.	2nd week.		B	A			E	1 day's rest.
Tues.					A			
Wed.								3 days' flying.
Thur.				E				
Fri.		D			E	A		
Sat.								3 days' rest.
Sun.								
Mon.	3rd week.		C	B			A	
Tues.					B			3 days' flying.
Wed.								
Thur.				A				1 day's rest.
Fri.		E			A	B		
Sat.								
Sun.								
Mon.	4th week.		D	C			B	7 days' flying.
Tues.					C			
Wed.								
Thur.				B				
Fri.		A			B	C		
Sat.								
Sun.								
Mon.	5th week.		E	D			C	
Tues.					D			10 days' rest.
Wed.								
Thur.				C				
Fri.		B			C	D		
Sat.								
Sun.								
Mon.	6th week		A	E			D	
Tues.					E			
Wed.								
Thur				D				7 days' flying.
Fri.								
Sat.		C			D	E		
Sun.								

TIME TABLE: ENGLAND—S. AFRICA.

Three Airships Required Lettered A, B and C Respectively.

Day.	England.		South Africa.		
	Arrival.	Depart.	Arrival.	Depart.	
Monday		A	C		
Tuesday				C	
Wednesday ...					
Thursday ...					7 days' flying.
Friday					
Saturday					
Sunday					
Monday		B	A		1 day's rest.
Tuesday	C			A	
Wednesday ...					
Thursday ...					
Friday					
Saturday					7 days'flying.
Sunday					
Monday		C	B		
Tuesday	A			B	
Wednesday ...					
Thursday ...					
Friday					
Saturday					6 days' rest.
Sunday					
Monday		A	C		
Tuesday	B			C	
Wednesday ...					
Thursday ...					
Friday					
Saturday					
Sunday					

TIME TABLE: ENGLAND—INDIA.

THREE AIRSHIPS REQUIRED LETTERED A, B AND C RESPECTIVELY.

Day	England. Arrival.	England. Depart.	South Africa. Arrival.	South Africa. Depart.	
Monday		A		C	
Tuesday					
Wednesday ...					
Thursday ...					6 days' flying.
Friday					
Saturday					
Sunday	C		A		1 day's rest.
Monday		B		A	
Tuesday					
Wednesday ...					
Thursday ...					6 days' flying.
Friday					
Saturday					
Sunday	A		B		
Monday		C		B	
Tuesday					
Wednesday ...					
Thursday ...					
Friday					8 days' rest.
Saturday					
Sunday	B		C		
Monday		A		C	
Tuesday					
Wednesday ...					
Thursday ...					
Friday					
Saturday					
Sunday	C		A		

Australia, taking practically the great circle course, advantage would be taken of the strong permanent westerly winds known as the "roaring forties." A complete new base with mooring mast would, of course, be required at Melbourne. For the return journey westward a course would be taken north of the outward journey, via Perth, where a mooring mast would be required, and advantage would be taken of the S.E. trade winds. The only small area of bad weather likely to be experienced would probably be between Madagascar and the African coast. It is considered advisable to place a mooring mast also in Ceylon, but were the return route made via Perth, Ceylon and Karachi you will see that it means crossing the monsoon area.

You have probably heard so much recently about the value of the mooring mast for ensuring regularity in airship traffic that I will not enlarge on the subject here, except to say that during the period of mooring mast experiments at Pulham, *i.e.*, from the 1st February to 30th June, daily flights were carried out, whereas at Howden without the mooring mast it was not possible to fly more than on thirty occasions, on account of not being able to get the ship out of the shed. This means 164 flights compared with 30.

There seems little doubt that following the steamship precedent, when airship traffic has become properly developed, the organisation will probably split itself into two companies—one to act as the air port or harbour company and the other to act as the operating company. I need not elaborate this point further; you will readily understand that the regulations which will have to be made regarding customs, fueling, etc., are bound to follow under these circumstances the lines of the conditions which exist in any maritime port.

(*b*) **Flying Organisation.**

I have appended three time tables which demonstrate how five airships would be required on the Australian route, three on the Indian route, and three on the South African route, in order to maintain a weekly service both ways to each of these three colonies.

Taking first the Australian route, you will see that this would consist of seven days flying to Africa, a day's rest there, and three days further flying to Australia. The ship would then rest for minor overhaul three days before starting on its return journey. Having reached England it would rest ten days before setting out again. Taking next the Indian route, the ship would do six days flying out, one day's rest in India, six days flying back, and eight days' rest before setting out again. Finally, for the South African route, the airship would take seven days flying out, one day's rest, seven days flying back, and six days' rest before setting out again. These estimates are based on the assumption that a ship will carry out a complete journey from England to, say Australia, with the same load of passengers and goods without any transhipment en route, or without carrying out any inter-port traffic. To begin with, this would undoubtedly represent the state of affairs. Later on it might be necessary to consider running certain ships continuously, say between England and Cairo only, other ships carrying on from Cairo on the three routes. The reason for this is that the conditions of temperature and weather, etc., are so entirely different in the two cases; thus, for the first part of the journey, in order to cope with high winds, it might be necessary to instal sufficient engine power to allow high speeds to be attained. In the latter case, owing to the high temperature and hence low density of the air, it might be more advantageous to have a larger ship with not such high engine power in order to obtain the necessary lift. As far as possible it would be arranged to land in the early morning and leave in the evening, because the temperature is at its lowest then and hence the ship has its maximum lift, also weather conditions are as a rule most settled at these times. Sometimes very considerable temperature gradients exist in the tropics,

and for the ordinary type of gradient where the temperature falls with the increase in height, the height of the mooring mast (150ft.) may mean that the ship is able to leave for this cause one ton heavier than if it had started from the ground. It is, of course, the object of a ship's pilot to maintain his ship continually in static equilibrium as far as possible. A certain amount of error either way can be corrected by the use of the elevators, but this reduces speed. On long flights a certain amount of this correction is inevitable in order to economise the gas, and the pilot must be continually studying this point and working out problems of lift, in which temperature, barometer and weight of petrol consumed are the chief items, always with an eye to what is likely to happen twelve hours ahead. Naturally in the morning when the temperature is rising he must do nothing which would jeopardise the safe landing in the evening when the temperature is falling, and vice versa, in the hottest part of the day he will fly under clouds, where they exist, in order to avoid excessive heating.

As you probably know, it frequently occurs that the temperature of the gas in the airship is different from that of the surrounding atmosphere. This is known as superheating, and is a disadvantage to the pilot in giving a false idea of the lift of the ship. Experience on this point in the tropics is much needed. In most cases it is due to the direct heat of the sun and is therefore likely to be most serious near the Equator. The sun's intensity tends to increase with height whereas air temperature generally decreases, so that to reduce superheating it is advisable to fly low. It is also advisable to fly fast, in order to take full advantage of the cooling effect of the air flowing over the outer cover. Another condition which may be frequently encountered in the Tropics is an inversion temperature, *i.e.*, the condition in which the temperature near the ground is lower than the temperature at a height. Under these circumstances, of course, superheating would only be increased by flying low. The inversion temperature may cause trouble when leaving the ground if it is unexpected, because if a ship leaves the ground so that it is only just light it will be practically impossible to force it through the hot air above.

For those who are sufficiently interested to go further into this matter they cannot do better than study the admirable lecture which Major Scott gave to this Society in London on December 2nd, 1920 [AËRONAUTICAL JOURNAL, Vol. XXV., p. 47]. In that lecture you will find he has dealt very fully with all the problems of this kind with which a pilot is likely to be confronted on a long distance colonial route.

(*c*) **Meteorology.**

A most important and vital factor in the final success of the colonial airship service will be the state of our knowledge with regard to the meteorology of the upper air. It is now fairly common knowledge that the state of the weather on the surface of the globe does not give much true indication of what is happening at heights of, say 2,000 feet and more. At the present time there is practically no data regarding the variation of wind velocities and direction with height. The data which are available chiefly deal with anti-cyclonic conditions when the air is clear and a pilot balloon can be sent to a great height. It would, of course, be rare under these conditions to have to alter altitude to avoid bad winds. Major Scott gives it as his general experience that westerly winds increase with height, whereas easterly winds tend to decrease, both tending to turn anti-clockwise. The forecasting of weather from cloud formations becomes a fascinating and important study. The worker at sea level is obviously at a great disadvantage here, however; his view may be obstructed by low clouds of very little use to him, and he only gains occasional glimpses of the upper and really important air. In the trans-Atlantic flight of R.34 it was found that the weather over the Atlantic undisturbed by land behaved in a most orthodox manner and little trouble was experienced in forecasting. It was also found that in a good

many cases shallow depressions, in which an adverse wind of as much as 45 knots might be experienced, did not extend to heights of more than 5,000ft. Semi-permanent winds were discovered following more or less the junction line of warm currents and cold arctic streams. These winds occur at quite low altitudes and will probably be of sufficient utility to make it important that they should be carefully charted. Electric storms are perhaps one of the airship's worst enemies; the serious bumps and eddies which occur subject the ship to very considerable strains. There is some evidence, however, that they are generally confined to certain areas and to certain periods of the year, and also that they follow a very definite track. Here again the charting of these is of utmost importance. It appears from the communique which the Air Ministry issued to the Press on May 31st regarding the formation of a commercial airship company that the Government would be willing to assist such a company with all the resources at their disposal in the study of meteorology and in forecasting, etc. This offer would, of course, be of great value. Generally speaking, the information which would be of most use to the pilot would not be a series of forecasts transmitted to him by wireless telegraphy, but such a thorough study of the annual weather conditions as to enable him to make his own forecasts whilst flying.

(*d*) Wireless Telegraphy.

Here again the Government have offered valuable assistance to a commercial airship undertaking. The study which requires most to be developed in wireless telegraphy in connection with airships is direction finding from the ship. The airship would require to carry a very high-powered installation for the direction finding to be done on land and the bearing transmitted to the ship. The scheme for an imperial wireless chain will ensure, it is hoped, a large number of high power stations being in operation in the not very distant future. If the airships are fitted with reliable direction finding apparatus they will be able to pick up these stations easily and obtain their own bearings.

(7) Financial Organisation.

I should perhaps apologise to a scientific society like this for introducing the subject of finance at some length. I feel, however, that no paper on the organisation of a colonial airship service would be complete without some reference to the financial aspect, especially at the present time when a good deal of nonsense is being talked about the prohibitive cost of airships for transport. I will make no attempt to deal with the development period as there are so many different ways in which this development may proceed, but I will consider the state of affairs which may be expected when a service of one ship per week both ways to each of the colonies, India, South Africa and Australia, has been properly established.

(*a*) Capital Costs.

The figures shown in Appendix I. are very similar to those given by the Imperial Air Communications Committee in their report, except that I have tried to present them in a more logical and intelligible form. With regard to the capital cost of twelve new airships, I am afraid I differ considerably from the estimate of the Committee. It is true that the rigid airships built by the British Government have cost on an average £350,000 each, but they have taken on an average one and a half years each to build and there has been no experience in building them on a production basis. The Germans reckon to take one year to produce a ship of an entirely new type, and after that two months for every ship of the same type on a production basis of say five ships. The Zeppelin Company built their ships during the war at a cost of about £150,000 and since the armistice have offered to sell the Americans a ship similar to those required for a

colonial service for £175,000. I therefore think that £200,000 is quite a fair estimate for ships built in England by a commercial concern on a production basis of twelve ships. My figures for the cost of a mooring mast station are slightly lower than those of the Committee, but they are nearly all taken from contractors' quotations, also I prefer to make an allowance for contingencies in a summary of costs at the end rather than to adopt the somewhat confusing practice of allowing for them several times over at various odd places.

The capital expenditure of new money required works out at about $4\frac{1}{4}$ million pounds (see Appendix I). A large sum, but not when the service to be rendered is considered. Not large in proportion when you consider the gigantic sums which have been sunk in harbours, docks, quays, lighthouses, etc., to aid steamship transport. No doubt a commercial concern would organise their bases, especially those abroad, so that the plant is fully utilised, possibly on engineering work of a local character in addition to its airship repairs, etc. Hydrogen plants might possibly be worked much more economically in conjunction with certain chemical manufactures. Pure hydrogen might be supplied for fat hardening or it might be produced electrolytically and the oxygen which is produced at the same time sold at a profit. One criticism which may be made of these estimates is that no allowance has been made for the purchase of land. You will readily understand that it is practically impossible to make even an approximate guess at this. Sites will necessarily have to be selected in the centre of low-lying ground, and if this is done a base will require about 500 acres and a mooring mast 200 acres.

(*b*) **Annual Expenditure.**

The question of annual expenditure is dealt with in Appendix II., under the headings of Maintenance Costs for Bases, Maintenance Costs for Mooring Masts, Annual Expenditure on Airships, Depreciation and Insurance. The maintenance costs which I have shown for Cardington are considerably lower than those given by the Imperial Air Communications Committee, but it should be borne in mind that the large part of the costs of labour at Cardington is included in the capital cost of building twelve new airships.

With regard to petrol, I have taken the figure of 2s. 6d. per gallon. The price has been reduced to this figure since the above Committee made their report, and there is little doubt that for a contract of 4,900,000 gallons per annum (which is the quantity that is estimated will be required), the price would be still further reduced.

Seven hundred million cubic feet of hydrogen will be required and I have put the price of this at 10s. per 1,000 cubic feet. I am fully aware that the Committee in their report have assumed the figure of £1 per 1,000 cubic feet, but this is the highest cost which has been experienced in the service for hydrogen production so far, and one of the largest manufacturers of hydrogen plants in this country has written to the Press saying that with modern developments and by the use of new plant, or with adaptations made to existing plants, the price need not exceed 6s. per 1,000 cubic feet. It therefore seems to me quite a fair compromise to take the figure of 10s. The figure of 7s. per day per person for passengers and crew has been included for food. As far as depreciation is concerned, the figure of $2\frac{1}{2}$ per cent. on buildings is a fair allowance for a factory plant and buildings, seeing that it covers all the items of capital expenditure and that liberal allowances have been made for maintenance. With regard to the airships, it is very difficult to form an exact estimate, as there are very few airships which have done sufficient continuous flying to show how long the structure will last, but granted that £10,000 per annum is being spent on each ship for material for maintenance, etc., the general opinion of the Germans and constructors in this country is that there is no reason why a ship should not last for five years. I have therefore taken the depreciation at 20 per cent.; 10s. per cent. has been

allowed as the usual figure for the insurance of the buildings and plant, but it is, of course, extremely difficult to say what is a fair rate for the insurance of the airships themselves. I have taken the figure of 5 per cent. It is possible that in the first place the company itself might be obliged to put aside a reserve fund for this purpose which might be considered as equivalent to insurance.

(c) Revenue.

The Imperial Air Communications Committee refrain with what is perhaps laudable temerity from attempting any estimates of the revenue to be derived from an airship service and draw attention to what they consider to be "the natural conservatism of the general public towards the adoption of new methods of transport." It would be rash indeed to attempt an exact forecast, but an examination of the existing volume of traffic together with the rates for freight and passengers reveal many interesting and helpful points. I have dealt with this subject in Appendix III.

Table A shows the present volume of traffic in first class passengers, parcels post, first class mail matter and certain items of special freight, some of which might possibly be carried by airship; unfortunately, I have not been able to obtain the tonnage figure for these items, but only the value. In Table B I have endeavoured to set out a possible estimate for traffic by airship. These figures are given with all reserve and are only intended to indicate some idea of the volume of traffic which would have to be carried to make the service a success, together with the revenue likely to be obtained under these conditions, with the rates shown.

As I have said already, a weekly service of one ship both ways to each of the colonies, Australia, India and South Africa, represents the minimum of what might be claimed as successfully improved rapid communication. I have also indicated that ultimately for a reliable service ships of four million cubic feet capacity will be required. The lift which such ships will have available for passengers and freight will be about 20 tons. Lest I should be accused of being unduly optimistic, I have based my estimates on the assumption that not more than two-thirds of their full capacity (*i.e.*, 14 tons) can be utilised. As far as passenger rates are concerned (in spite of the conservatism which may be experienced at first against this new form of transport), I feel that these will have to be kept as near as possible to existing steamship rates so as to attract as many people as possible at a low rate rather than a few at a high rate. It is only thus that the public will be educated to realise that the airship is not the precarious uncomfortable craft they imagine it to be at present. You will see that the passengers to be carried by airship according to Table B represent one quarter of the number of first class passengers which at present travel by other means. It does not seem to me at all unreasonable to suppose that this number could be attracted to travel by airship in the not very distant future, when one considers the benefits to be secured from the enormous saving in time. The great advantage of personal contact in business is only one factor which will cause many more to travel than before, and hence the volume of traffic will be automatically increased. The comfort of travel is another important factor. I will not hesitate to say that anyone who has taken a trip in an airship, such as R.36, will tell you that they cannot imagine a more easy and comfortable means of travelling.

To quote Sir Halford Mackinder, Chairman of the Imperial Shipping Board, "The airship offers the most satisfactory method of long distance travel yet invented." I would like to further quote so eminent an authority on another aspect of this question of passenger traffic by airship. How far will airship traffic react on existing means of long distance transport? What will be the effect on shipping companies and how will they regard it? Sir Halford Mackinder says:—

"Statesmen and merchants are in a hurry when they cross the world, but emigrants and cargo need cheap and therefore relatively slow carriage. Only in the case of the North Atlantic have you such great and wealthy populations on either side that you can retain a 25 knot service for passengers and leave cargo to be carried by tramps and the slower liners.

"In the Australian trade a compromise must be struck, for Australia and New Zealand have together only seven million people. While statesmen and merchants call for 20 knots an hour, and cargo can be most economically transported at 10 knots an hour, the statesmen and merchants are carried, grumbling, at 14 knots and the extra cost of pulling cargo along at such a pace is shared between them and the shippers, who, also grumbling, must pay higher freights than would otherwise be necessary.

"Steamships will in future be built of the most economical tonnage and speed, for they will no longer have to cater for passengers to whom time is more important than cost. Cargo and emigrants will, therefore, be carried at the lowest possible charges, a matter of vital significance, especially to Australia and New Zealand, both of them hungry for capital and for white population."

Similarly with regard to mails, half of which the table suggests should be carried by airship. At least half the first class mail must be business matter and I cannot imagine any business man objecting to paying 9d. and 6d. per oz. to Australia and India respectively when the saving in time will mean a definite increase to his business turnover. The interest to be saved on credit documents of all kinds by such rapid transport should surely prove a great attraction to him also. With adequate Government support, therefore, there appears to be no reason why the revenue to be derived from mails should not be of the order shown.

The question of how soon the specified amount of special freight traffic will be forthcoming turns very largely on how soon the insurance of such goods can be effected at a stable and reasonable rate. Let us hope that in the development period the airship will have so proved its capability for regular and safe transport as to enable this rate to be laid down with certainty. I have given some figures in Table A of some of the sources from which special airship freight might be drawn. The remarks I have just made with regard to the saving in interest on credit documents equally apply to bullion. Returns made in 1920 show that the bullion imported from South Africa was about £38,000,000 and that exported to India was £36,000,000. Assume that the time of transit in both cases is cut down from 21 to 7 days, then the saving on interest for 14 days at 5 per cent. on £74,000,000 works out at £154,000 approximately.

(*d*) **Cost Summary.**

Having dealt with the questions of capital costs, annual expenditure, and annual revenue, I will now summarise these figures, making certain additions for contingencies.

Annual Expenditure (approx.)	£2,350,000
Add for Contingencies	250,000
	2,600,000
Annual Revenue (approx.)	3,150,000
Annual Profit	550,000
Capital Expenditure (approx.)	4,350,000
Add for Contingencies	500,000
	£4,850,000

It will be seen that even with these liberal allowances for contingencies the annual profit represents 11 per cent. of the capital expenditure. Again let me emphasise the fact that the revenue figures are given with all reserve; the figures for capital and annual expenditure are, I think, fairly reliable. Once the service has worked up the traffic shown in Appendix III. there is no reason why it should not be quite a paying concern. This will take time, the development period will be a trying one during which any company will require large subsidies to enable it to raise the necessary capital to get going at all.

(8) Future Technical Development in Commercial Airships.

It was inevitable that the incentive of war produced very rapid developments in the construction of airships. Since the armistice the advances made have of necessity not been so great, nor yet so spectacular, but definite advances have been made, notably the development of the mooring mast. What is perhaps still more important is that a number of researches are just being brought to fruition, and these should have far-reaching effects. For this reason it is most unfortunate that the halt, not only in airship flying but also in research, should have been called at the present moment, leaving a number of valuable investigations so to speak in the air.

I will briefly outline some of these experiments and also some of the technical needs of the commercial airship of the future in the hope that they will stimulate the attention of engineers and men of science and that the new lines of thought will be productive of useful discussion.

(*a*) The Airship Hull.

You are all probably familiar with the general construction of the hull of a rigid airship. Although advance has been made in the various elements of the hull, there has been little or no tendency to depart from the general principle of the structure built up of transverse rings and longitudinal girders with the appropriate wiring. Alternatives have been suggested, such as a strong central beam with radiating spokes, and also a system in which the girders are arranged spirally round the hull from end to end. These ideas have not found favour with airship designers, either in this country or in Germany. Considerable success has been attained, however, with semi-rigid airships of fair size, and it is claimed for the Parseval semi-rigid P.L.26 that her performance was actually better than the Zeppelin rigid "Bodensee," which had about the same gross lifting power. Careful consideration should be given to the problem of determining up to what size, if at all, the semi-rigid possesses advantages over the rigid. Also it may be found that a type which is a compromise between the two might be successful up to still greater sizes.

Referring to the present scheme of hull construction, there is still room for considerable improvement. The original material used by the Zeppelin Company was aluminium. Their rivals, the Schutte-Lanz Company, who incidentally were responsible for a good many of the improvements contained in modern rigids, decided that wood was a superior material to aluminium. Later on the Zeppelin Company countered this by the use of duralumin, which is definitely superior to wood. This forced the Schutte-Lanz Co. to also consider duralumin construction, and they claim to have definitely made an advance on the methods of their rivals in using a tubular form of duralumin construction in their S.L.23. This ship was never completely assembled and most of the parts were destroyed or hidden before the Commission of Aeronautical Control arrived in Germany. As far as can be ascertained, however, plant had been put down for what had proved to be a perfectly satisfactory type of girder construction on tubular principles. The ship was to be one of about 2¼ million cubic feet capacity, which you will see is no larger than existing rigids and was definitely lighter for the same strength than

a ship built on the well-known Zeppelin principles. We have not been idle in this country on the same type of construction, but I am not at liberty to give you any further details at present. I think it fairly safe to predict, however, that the new ships of the immediate future will most probably be built on these lines. In changing over from airships designed for war purposes to those intended for commerce, it is probable that performance may have to be sacrificed for the sake of ruggedness of construction.

The question of the use of steel for the girder construction has been carefully considered. The Germans hold the opinion that this would not be satisfactory until capacities of over 8 million cubic feet are reached, and I think I am right in saying that airship constructors in this country would not care to use steel for a ship of less than 10 million cubic feet capacity. Research on an aluminium alloy to replace duralumin has attained very considerable success. This alloy should definitely prove superior from a mechanical point of view and is certainly much cheaper.

(*b*) **Gasbags.**

The present system of constructing gasbags of light cotton fabric lined with goldbeater's skin is, as you are probably aware, a very tedious and costly one. The amount of labour involved is very considerable indeed, and it is safe to say were airships being used in comparatively large numbers, owing to their commercial development, the supply of goldbeater's skin in the world would not be sufficient to meet the demand. Work has been going on for a long time on a synthetic form of goldbeater's skin, which can now be made in long continuous rolls with an adhesive face and can be attached to the cotton by merely running the two materials through a callender. The Air Ministry were about to place a contract for two experimental bags made of this material when the order came to cease all further work.

(*c*) **Hydrogen.**

The cost of hydrogen forms a very considerable item in the airship budget. The methods used for the production of hydrogen, both in this country and in Germany, had not been improved to any great extent by the end of the war. The method used is that known as the iron and steam contact process, in which iron is alternatively oxidised and reduced, the only difference being that in this country the multi-retort type of plant was used, whereas in Germany they developed the single reaction chamber type. The maximum thermal efficiency of either of these types is not much more than 15 per cent., and they were designed in pre-war days when coke was cheap. There is little doubt that great economies can be effected in this direction, and one of the big companies concerned in the manufacture of hydrogen plants are now giving the matter their careful attention, and consider that economies of 60 per cent. on the price of £1 per 1,000 cubic feet can be effected. The question of the production of hydrogen at stations abroad is a more difficult problem owing to the cost of fuel. In this connection some interesting experiments are in progress with the fermentation of vegetable matter. The results so far indicate that this is quite a hopeful field of research. The large quantity of matter available in Egypt, known as Nile sudd, is particularly interesting in this connection.

It is of the utmost importance to maintain a high purity in an airship itself because the loss entailed by the additional load of air carried is very considerable. As an example, in a 4 million cubic feet ship a drop of 1 per cent. in the purity produces an additional load of approximately one ton of air, which means, of course, an actual loss of one ton of cargo carrying capacity. It is a comparatively easy matter to get rid of the oxygen in the contaminated gas, but the nitrogen is a far more difficult problem.

You are all probably aware of the fact that, generally speaking, an airship has to valve a considerable amount of gas before landing, owing to the fact that she has become light during a journey by the weight of the fuel which she has burnt. One method of avoiding this waste would be to take some form of ballast on board whilst in flight were this possible. Experiments in condensing the water in the exhaust of the engines in order to gather ballast by this means have been commenced, but have not proceeded far enough to show whether they are likely to be ultimately successful or not. A better means of tackling the same problem would be to burn the hydrogen (which would otherwise be wasted) as engine fuel. It has not been found satisfactory to burn hydrogen alone in an aero engine, because it detonates very easily if more than about half full power is being developed. Researches which are being carried on at present, however, indicate that it is quite possible to use hydrogen in conjunction with petrol, and the saving which will be effected thereby is very considerable indeed. In fact, it may be said that it might possibly increase the radius of action of the airship by 50 per cent. If it were possible to use hydrogen in conjunction with crude oil the inflammability of the ship would be reduced enormously. This has yet to be investigated.

(*d*) Engines.

There are reasons why a ship of a given size should have a number of engines of a certain horse-power rather than a fewer number of engines of a greater horse-power. Apart from the question of excessive concentration of load and thrust produced by engines of too great a horse-power, a large range of speeds will be obtained with greater economy by putting a certain power into a certain number of engines, rather than putting greater power into a fewer number of engines. It is considered that for airships up to 4 million cubic feet capacity engines of not more than 600 h.p. should be used. So far a satisfactory airship engine of this power has not been produced, and in the design of such an engine full account must be taken of the different conditions under which an airship engine has to run as compared with an aeroplane engine. The engine should be capable of running economically over a wide range of speeds without serious vibrational periods and also should be capable of running light without oiling up. The maximum efficiency of the engine should occur at that speed at which the engine may be run continuously for long periods. In this respect a good many aeroplane engines are unsatisfactory. It often occurs that an aeroplane engine when run at its maximum power on a test bench does give the maximum efficiency, but in flight for various reasons the maximum power is not obtained and then the engine performance falls considerably below that of maximum efficiency.

(*e*) General.

For the purposes of economy of both time and expense it will be necessary to have the various parts of the commercial airship as easily replaceable as possible. It will have to be a simple and inexpensive matter to replace faulty or damaged girders, and as far as engines are concerned it will be necessary to have a unit which can be readily detached as a whole and which is interchangeable. The design of such a standard power car containing such accessories as a variable pitch propeller and exhaust heated steam boiler, etc., has been completed. The question of the heating, sanitation and lighting of the ship is one which needs a considerable amount of attention.

Somewhat erroneous ideas exist as to the dangers of fire in an airship. Fire may be due to two causes, the ignition of petrol or the ignition of the hydrogen

gas. If either of these has become sufficiently mixed with air the ignition may take the form of an explosion. Experience has shown that of the two causes the petrol vapour is by far the more serious. As I have already hinted, a solution to this is by the use of a heavy oil with a high flash point and research on this is going on. With regard to the hydrogen, generally speaking, in the ship the danger is not so serious as is commonly imagined, especially as the hydrogen cannot burn or explode until it has free access to the air. The use of helium to replace hydrogen, as I have already stated, has attracted a good deal of attention, especially in the United States, but the purification of the helium from the natural gas in which it occurs is a very costly business; also the known sources of supply are so very few that I have grave doubts as to whether the use of helium in commercial airships will ever become a practical proposition. It is quite probable, however, that sufficient helium could be stored to fill airships in wartime which had been normally flying filled with hydrogen. Research is more likely to take the lines of preventing all chances of a light getting to the gas, and in this respect it is not at all out of the question that on an airship of say 5 million cubic feet capacity an all-metal cover could be used. In the event of commercial airships being commandeered for naval or military purposes in wartime, the prevention of fire from incendiary bullets might also be effected in another way. It is possible that an envelope of nitrogen might be arranged to surround the gasbags in the space between them and the outer cover. Experiments have been conducted with a double balloon in which the outer space has been filled either with nitrogen or with the exhaust gases from an engine. In both cases incendiary bullets failed to ignite the hydrogen.

In the event of an airship finding itself over the sea with so little fuel as to very greatly limit her motive power, surface craft provided with mooring masts on them might be sent to its assistance. Experiments have already been made with the refuelling of an airship when attached to the mast of a surface craft which are very promising.

(9) The Imperial Benefits of a Commercial Airship Service.

The war gave this Empire a great lead in aircraft matters, and surely that lead should be jealously guarded now that peace has called on us to fly our aircraft to commercial uses. We have jealous rivals abroad, especially as far as airship matters are concerned. With airships as with aeroplanes, I cannot help sharing the opinion which has been so often expressed by many eminent authorities, that the country which would have the most powerful air arm for military necessity in future would be the one which has the most flourishing commercial air services from which it can draw aircraft in case of sudden necessity. Similarly with regard to bases and aerodromes. A well-established chain of commercial bases would be of immense value to military aircraft in time of necessity, but the cost of maintaining such bases in peace time for military preparations alone would be considerable and uneconomical. As a parallel case one may quote the fact that naval bases, landings, harbours, etc., are seldom, if ever, used by mercantile ships in peace time, whilst on the other hand, mercantile harbours are of very definite use to battleships in time of war. It is no secret that our naval authorities do still attach very considerable importance to the value of airships in assisting naval operations, and, in fact, I doubt if they would ever have consented to the complete abandonment of airships in this country had they not at the back of their mind some sort of assurance that a commercial undertaking would ultimately be formed to operate airships. On this they could draw in time of urgent necessity, very much in the same way as the navy itself originally grew out of our powerful mercantile marine. In this respect it will surely be conceded that the prestige which the British Empire would gain from a service of airships operating amongst its members would be enormous. It is

probably not fully realised that a modern airship could keep something like 100,000 square miles under observation in 24 hours, a task which would require at least six fast surface craft. Had we a proper system of airships guarding our trade routes during the recent war, I think that the career of the "Mowe" and the "Wolf" would have been a very short-lived affair.

His Majesty the King, in his reply to the loyal address of the Dominion Premiers, issued a call to the men of science to find some more rapid means for linking up the far-reaching boundaries of the Empire with the Motherland. I would humbly suggest that one of the many benefits which have been derived out of the terrible scourge of the war is that the men of science have already provided such an instrument in the airship, which I maintain is quite capable of fulfilling His Majesty's hopes and wishes in this respect.

(10) Conclusion.

I cannot close without some further slight reference to the tragic disaster of R.38. You will all have probably read by now the findings of the Service Court of Inquiry. A further very technical inquiry is being conducted which, I cannot help feeling (except for supplying further technical details), will only tend to confirm the general spirit of the findings of the Service Court. The lessons to be derived are quite clear and it is essential that the general public should fully understand these lessons, and not view the situation in any spirit of prejudice. The idea that the airship was lost for any mysterious cause should be completely dispelled. Such an idea naturally creates in the public mind the impression that there is something inherent in the nature of the airship which we do not know and which is, therefore, a continual and potential source of danger as we are unable to cope with it. The R.38 was an airship of a highly experimental character, calculated to give a performance for military purposes very considerably in advance of anything which had been built before. She was lost whilst carrying out trials of a highly strenuous nature, but not more strenuous than any commercial airship would be subjected to before it was allowed to carry passengers. I have little doubt that R.34 in crossing the Atlantic was subjected to far greater strains than was R.38 during her trials. As I have already indicated, the whole tendency in designing commercial airships would be to increase their ruggedness, even at the expense of making their performance less high than the performance called for in military ships during the war. With a ship cut down to such fine limits as was the R.38, every little portion of design requires most careful scrutiny. For this reason any lack of information on relevant aerodynamical data could be ill afforded. That some of these data were lacking there seems little doubt from the remarks of the Court of Inquiry. This surely points to the necessity for most careful and patient research on all scientific problems connected with the airship, including those on the aerodynamics of the subject.

At present in this country all airship research is at a standstill and, therefore, I cannot too highly commend the far-seeing and public-spirited attitude of this Society in endeavouring to raise a fund for airship research as a memorial to those who lost their lives in R.38. One thing more, it should be clearly realised that, although probably the majority of lives were lost through the fire and explosions which occurred, this fire only occurred as a result of the hull of the ship breaking into two portions. You will see, therefore, that it would be as unreasonable to say that railway travel was unsafe, owing to the dangers of fire, because in many cases of railway accidents trains have been badly burned, as it would be to say that airship travel can never be successful owing to the danger of fire which might occur, as in the case of R.38.

APPENDIX I.

CAPITAL COSTS (NEW EXPENDITURE).

Ships.

Twelve ships at £200,000 = ...		£2,400,000

Mooring Masts.

Re-erect Croydon mast at Cardington ...		4,000
Cardington, Cairo, S. African route (2), India, Ceylon, Perth, Melbourne	8 at £47,600* = ...	380,800

Bases (Masts for these included in the above).

Melbourne (new) = ...		400,000
S. Africa (new) = ...		400,000
Cairo—		
Transport and erect existing shed ...	£150,000	
Hydrogen plant ...	10,000	
Gasometer ...	20,000	
Gas main ...	4,000	
Buildings ...	10,000	
Equipment ...	4,000	
Petrol storage ...	4,000	
Roads and siding ...	20,000	
Transport ...	15,000	
		237,000
Cardington—		
Two new sheds ...	500,000	
Lengthen existing shed ...	15,000	
New gas main ...	2,000	
		517,000
		£4,338,800

***Details of a mooring mast station.**

Mast ...	£2,700	
Masthead ...	500	
Three winches ...	1,400	
Electric motors ...	500	
Pumps ...	200	
Lift ...	900	
Mains ...	2,000	
Cable ...	2,000	
Foundations ...	400	
Petrol storage ...	2,000	
Gasometer ...	20,000	
Gas main ...	2,000	
Gas plant ...	6,000	
Buildings ...	1,000	
Equipment ...	2,000	
Roads ...	1,000	
Transport ...	3,000	
		£47,600

APPENDIX II.

ANNUAL EXPENDITURE.

Bases.	Cardington.	Cairo.	S. Africa.	Melbourne.
Maintenance of base	£10,000	£10,000	£10,000	£10,000
Electric light and power	5,000	5,000	5,000	5,000
Advertising and office expenses ...	10,000	6,000	6,000	6,000
Personnel, wages and salaries ...	55,000	40,000	40,000	40,000
Transport	1,500	1,500	1,500	1,500
	£81,500	£62,500	£62,500	£62,500

Total £269,000

Mooring masts (9)

Maintenance	£1,000
Electric light and power	1,500
Advertisement and office expenses	1,000
Personnel, wages and salaries	7,000
Transport	1,000
	£11,500

Nine masts at £11,500 ... ... Total £103,500

Ships (12).

Crews (12) at £12,000 each = ...	£144,000
Petrol (4,900,000 galls. at 2s. 6d.) = ...	612,500
Hydrogen (700 million cu. ft. at 10s. per 1,000) = ...	350,000
Food for crews and passengers	51,500
Material for maintenance (labour is allowed for in base personnel)	120,000

Total £1,278,000

London office expenses £30,000

Depreciation.

Buildings and plant, 2½% on £2,200,000	£55,000
Airships, 20% on £2,400,000	480,000

Insurance.

Buildings and plant, 10s. % on £2,200,000	£11,000
Airships, 5% on £2,400,000	120,000

Grand total £2,346,500

APPENDIX III.

Table showing the yearly traffic of 1st class passengers, mails, parcels post, and certain items of special freight between Great Britain and Australia, South Africa and India.

TABLE A.

Colony.	1st Class Passengers.				1st Class Mail Matter.				Parcels Post.						Special Freight.					
	Number.			Fare.	Tons.			Rate	Number.			Total tonnage (approx.)	Total value.	Rates.	Total value in and out.					
	Out.	In.	Total.		Out.	In. approx.	Ttl. approx.		Out.	In.	Total.				Diamonds.	Fur.	Feathers.	Chemical Preparations.	Drugs.	Scientific apparatus (including films).
Australia, Tasmania, and New Zealand	4,895	3,103	7,998	£175 (Sydney).	162	150	312	2d. for the first oz. 1½d. each additional oz.	213,965	58,672	272,637	364	£486,600	1/4 the first lb. 6d. each additional lb.		£390,772		£531,331	£431,501	£261,830
South Africa (including the Cape, Transvaal, Natal and Orange Free State).	8,677	6,652	15,329	£97 (Cape).	185	170	355		187,526	53,141	240,667	322	£428,193	9d. per lb.	£5,470,899	£337,806	£1,232,161	£671,750	£192,886	£75,102
British India (including Bombay, Madras, Bengal and Burmah).	14,637	11,586	26,223	£90 (Bombay).	255	230	485		312,516	115,879	428,396	573	£740,908	Up to 3 lbs. 1/9, 7lbs. 3/6, 11 lbs. 4/9.		£460,905		£446,047	£521,131	£158,528

The figures for special freight and parcels post are from Board of Trade Returns for 1914.
" " " passengers and mails are from official figures for 1920.

APPENDIX III. (*continued*).

Table showing sketch estimates for the yearly traffic of passengers, mail and special freight with airships carrying out one trip per week both ways, utilising approximately two-thirds of their full capacity, *i.e.*, 14 tons (a 4,000,000 cub. ft. ship would have a capacity of 20 tons).

TABLE (B).

Colony.	There would be 104 trips per year. Assume that the *14 tons available on each trip is divided as shown.	Passengers.				Mails.			Special Freight.		
		Number.	Wt. Tons.	Fare.	Total Revenue.	Tons.	Rate.	Total Revenue.	Tons.	Rate.	Total Revenue.
Australia ...	30 passengers and baggage = 5 tons ... Mail = 2 tons ... ... Special freight = 7 tons	3,120	520	£200	£624,000	208	9d. per oz.	£279,552	728	6/- per lb.	£489,216
S. Africa ...	40 passengers and baggage = 6½ tons ... Mail = 2 tons ... ... Special freight = 5½ tons	4,160	676	£100	£416,000	208	6d. per oz.	£186,368	572	4/- per lb.	£256,256
India ...	50 passengers and baggage = 8 tons ... Mail = 2 tons... ... ... Special freight = 4 tons	5,100	832	£100	£520,000	208	6d. per oz.	£186,368	416	4/- per lb.	£186,368
			TOTAL REVENUE ...		£1,560,000			£652,288			£931,840
									GRAND TOTAL ...		£3,144,128

Comparing the above figures with those given in Table A, it will be seen that the total number of passengers proposed to be carried by airship represents 25% of those travelling at present by other means ; the amount of mail proposed to be carried by airship is 54% of the amount of mail carried at present by other means. It is difficult to find a basis of comparison for the special freight proposed to be carried—it represents, roughly, 1½ times the present weight of packages carried by parcels post.

* Representing two-thirds of full capacity.

PUBLICATIONS.

The following papers, etc., are published by the Society in addition to the JOURNAL:—

Transactions.

1.	"The Calculation of Stresses in Aeroplane Wing Spars," by Arthur Berry, M.A.	5s.	od.
2.	"Position Fixing in Aircraft during Long Distance Flights over the Sea," by Instructor-Commander T. Y. Baker, R.N., and Major L. N. G. Filon, D.Sc., F.R.S., late R.A.F. ...	5s.	od.
3.	"Aero Engine Efficiencies," by Dr. A. H. Gibson	5s.	od.

Aeronautical Classics.

Reprints of the Work of Early Pioneers on whose theories modern flight is based.

1.	"Aerial Navigation," by Sir George Cayley (1809)	1s.	od.
2.	"Aerial Locomotion," by F. H. Wenham (1866)	1s.	od.
3.	"The Art of Flying," by Thomas Walker (1810)	1s.	od.
4.	"The Aerial Ship," by Francesco Lana (1670)	1s.	od.
5.	"Gliding," by Percy S. Pilcher (1897)	1s.	od.
6.	"The Flight of Birds," by G. A. Borelli (1680)	1s.	od.

Miscellaneous Publications.

"Steels Used in Aero Work," by Dr. W. H. Hatfield	5s.	od.
"Methods of Measuring Aircraft Performances," by Captain H. T. Tizard	1s.	6d.
"The Screw Propeller in Air," by M. A. S. Riach	2s.	6d.
"The High Tension Magneto," by A. P. Young	5s.	od.
"Commercial Aeronautics," by G. Holt Thomas	2s.	6d.
"The Training of Aeronautical Engineers," by R. M. Walmsley and C. E. Larard	2s.	6d.
"Steel Tubes for Aircraft," by W. W. and A. G. Hackett ...	2s.	6d.
"Timber," by W. H. Barling	5s.	od.
"Design of Aeroplane Struts," by W. H. Barling and H. A. Webb	2s.	6d.
"Stress Optical Experiments," by Major A. R. Low	5s.	od.
"Medical Aspects of Aviation," by Dr. L. E. Stamm	2s.	6d.
"Struts of Conical Taper," by H. A. Webb and Miss E. D. Lang	1s.	6d.
"Shop Practice in Respect to Aircraft Steel," by H. P. Philpot ...	5s.	od.
"The Rigging of Aeroplanes," by R. J. Goodman Crouch ...	5s.	od.
"Progress of Aviation during the War Period," by Dr. L. Bairstow	5s.	od.
"Flight of Seagulls," by Dr. E. H. Hankin	1s.	od.
"Chronology of Aviation," by H. Maxim and W. J. Hammer ...	1s.	od.
"Report of the Bird Construction Committee"	10s.	6d.
"Glossary of Aeronautical Terms"	2s.	6d.
"London-Paris Service. Safety and Economy Committee's Report"	1s.	6d.

THE

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All communications should be addressed to the Editor.

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Notices of the Royal Aëronautical Society.

Election of Members.

The following Members were elected by the Council during the month:—

Fellow.—Major D. H. Kennedy.

Associate Fellows.—H. D. Boultbee, B. W. O. Townshend, H. M. Yeatman.

Technical Discussions.

It has been decided to hold from time to time technical meetings in the Society's Library for the purpose of discussing scientific papers of a more intricate character than those which are suitable for the Society's lecture programme. Any papers submitted will first be considered by the Library and Publications Committee, when, if approved, a date will be fixed for their discussion. A limited number of advance proofs will be prepared and distributed only to members who apply for them, or invited guests. The meetings will consist of discussion only on the assumption that the paper has been previously read by all present. The papers may subsequently be published in the Journal together with the discussions thereon, each individual forwarding his contribution to the Secretary in writing for this purpose.

Memorial Lectures.

In addition to the Wilbur Wright Memorial Lecture, which was constituted in 1912 and for which a capital sum exists in the hands of Trustees sufficient to pay an annual fee of £50, a fund has lately been raised by private subscription to provide a small fee for an annual lecture in memory of the late Wing Commander Nevill Usborne, who played so important a part in the early development of British airships. It is proposed to hold the first Usborne Memorial Lecture in 1922.

Students' Discussion Meetings.

The Monthly Discussion Meetings held in the Society's Library are meeting with welcome support from Student Members. At the second meeting on Thursday, November 10th, Mr. W. L. Le Page read a paper on "The Soaring

Flight Problem," when Mr. F. Handley Page, Fellow, took the chair. These meetings are confined to student members of the Society and their friends, and at the end of the Session the Pilcher Memorial Prize will be awarded to the paper inaugurating discussion at one of these meetings which is judged by the Council to be the best.

R.38 Memorial Research Fund.

The following further donations to this Fund have been received since the publication of the last list in the November issue, bringing the total up to and including November 14th to £1,093 6s. 6d.

	£	s.	d.
Lord Invernairn	105	0	0
W. H. Coats, Esq.	105	0	0
Viscount Cowdray	52	10	0
Viscount Burnham (Proprietors of "Daily Telegraph") ...	25	0	0
Sir John Hunter	20	0	0
Sir Archibald Denny, Bart.	15	15	0
Sir H. McGowan	10	10	0
G. Holt-Thomas, Esq.	10	10	0
Sir Joseph Maclay	10	10	0
Lord Foley	10	0	0
Lieutenant-Colonel J. Dunville	10	0	0
H. E. Yarrow, Esq.	10	0	0
Lord Glentanar	10	0	0
J. E. Hodgson, Esq.	5	5	0
R. P. Wilson, Esq.	5	5	0
Flight-Lieutenant R. S. Booth	5	0	0
Lord Montagu of Beaulieu	3	3	0
Major-General Sir Sefton Brancker	3	3	0
Anon.	3	0	0
A. H. Ashbolt, Esq.	2	2	0
A. P. Cole, Esq.	2	2	0
H. Wyn Evans, Esq.	2	2	0
Rev. Basil Phillips	1	1	0
E. H. Lewitt, Esq.	1	1	0
John Newton, Esq.	1	1	0
S. E. Taylor, Esq.	1	0	0
Flight-Lieutenant John Barron	1	0	0
Captain A. E. Heatley	0	10	0
Major G. H. Abell (Second donation)	0	10	6
Captain J. B. Walker	0	5	0
	£432	5	6

Prizes.

The Council will, at the New Year, consider the award of the Society's Silver Medal to the author of the best paper published in the Journal during the year. The Society's Bronze Medal is similarly open for annual award to the best paper by a Student Member published in the Journal.

Donations.

The Council acknowledge with grateful thanks the gift of the following books from Air Commodore H. R. M. Brooke-Popham on vacating the chair:—"Manual of Meteorology, Part IV.," by Sir Napier Shaw; "The Gas, Petrol and Oil Engine," by D. Clerk and G. A. Burls; "The Heat Treatment of Tool

Steel," by H. Brearley; "Thermodynamics for Engineers," by J. A. Ewing; "Theory of Structures," by Arthur Morley.

Lectures.

The following amended programme of lectures for the remainder of the present Session is published for the information of Members :—

Dec.	1.	"The Present State of Airship Development." Major G. H. Scott.
,,	15.	"Development of the Fighting Aeroplane." Capt. F. M. Green.
1922.		
Jan.	5.	"Specialised Aircraft." Wing Commander W. D. Beatty.
,,	12.	Juvenile Lecture. (To be announced later.)
,,	19.	"Aeroplane Installation." Brig.-Gen. R. K. Bagnall-Wild.
Feb.	2.	"Radiological Research and the Examination of Materials." Dr. V. E. Pullin.
,,	16.	"Methods of Instruction in Aeroplane Flying." Squadron Leader C. F. A. Portal.
Mar.	2.	"Testing Aircraft to Destruction." W. D. Douglas.
,,	30.	"The Design of a Commercial Aeroplane." Capt. G. de Havilland.
Apl.	6.	(Subject to be announced later.) Mons. L. Breguet.

The lectures will be held in the Theatre of the Royal Society of Arts, John Street, Adelphi, at 5.30 p.m.

Arrangements for the Month.

Dec.	1, 5.30 p.m.	Lecture by Major G. H. Scott, C.B.E., A.F.C., on "The Present State of Airship Development," Royal Society of Arts, Adelphi, London.
,,	8, 7.0 p.m.	Students' Discussion Meeting, C. Daniel on "Practical Points in Fuselage Construction," in the Society's Library.
,,	12, 8.0 p.m.	*Scottish Branch.*—Lecture by Colonel Gold, of the Meteorological Dept., Air Ministry, on "The Application of Meteorology to Aviation," Royal Technical College, Glasgow.
,,	15, 5.30 p.m.	Lecture by Captain F. M. Green on "The Development of the Fighting Aeroplane," Royal Society of Arts, Adelphi, London.
,,	16, 4.0 p.m.	Candidates' Committee Meeting.
,,	16, 4.30 p.m.	Publications and Library Committee.
,,	16, 5.0 p.m.	Council.

W. LOCKWOOD MARSH,
Secretary.

PROCEEDINGS.

SECOND MEETING, FIFTY-SEVENTH SESSION.

A meeting of the Society was held in the Hall of the Royal Society of Arts, London, on Thursday, October 20th, 1921, Lord Montagu of Beaulieu presiding.

The CHAIRMAN said that they were gathered there to hear a lecture which he was sure would interest them all. It raised, he understood, some points which might be described as controversial, but he did not think anybody minded controversy if it led to establishing the real truth and put on record what should be the history of the past.

As regarded the lecturer himself, he need hardly introduce Mr. Griffith Brewer. He was one of the oldest of those who had taken an interest in aviation, from the days of ballooning to the various methods of progress through the air to-day. There was nobody more qualified to read a paper on this subject, and he was quite certain that, whatever their personal opinions might be in regard to the controversy, they would all thank him very much for having gone so carefully into the question, which was important on both sides of the Atlantic.

In order that there might be no misapprehension as to the facilities given for reply, he was informed that a full copy of the paper, with the diagrams and photographs, had been forwarded to the following American gentlemen mentioned in the paper:—Dr. Walcott, Mr. Manly, Dr. Zahm and Mr. Glenn Curtiss. They had all been invited to come and take part in the discussion, if they could, or send a written contribution. Replies had been received from Mr. Curtiss and (a cable) from Dr. Walcott. They had not yet arrived, but were in the mail. He wanted to make it clear that the Society had given, and would give, every opportunity for both sides of the question to be heard, and it went without saying that when Dr. Walcott's and Mr. Curtiss's replies were received, together with any others that were sent, they would be printed with Mr. Griffith Brewer's paper in the December number of the AERONAUTICAL JOURNAL.

The chief duty of the Chairman of such a gathering as that was to say as little as possible himself and make way for the lecturer, so he called upon Mr. Griffith Brewer to read his paper.

Mr. GRIFFITH BREWER then delivered the following lecture:—

THE LANGLEY MACHINE AND THE HAMMONDSPORT TRIALS.

In the discussion following my reading of the Wilbur Wright Memorial Lecture, before the Royal Aeronautical Society, on June 6th, 1916, Lord Northcliffe drew attention to the attempt which had been made to rob the Wright Brothers of the credit of inventing the aeroplane.

> "We have not heard much of that in England," said Lord Northcliffe, "but 'a prophet is not without honour save in his own country,' and in the United States there have been long and persistent attempts to belittle the work of Wilbur and Orville Wright. I have closely read and followed the history of the hundred years of aeroplane experiments, and I am convinced that the credit of the first flying machine is due to the Wright Brothers, and from the point of practical flying to nobody else. As an Englishman I am in an independent position, and I know that these words of mine will

go across the Atlantic, and I believe they will assist in stopping the spread of the insidious suggestion that the Wrights did not invent the aeroplane."

The omission in my Paper, referred to by Lord Northcliffe, was due to the fact that I had not sufficient facts at that time to completely disprove the good faith of the endeavours which were being made to prove that it was Langley and not the Wrights who had brought in the era of practical flying. I had, however, already in America in 1914 commenced some investigations into these attempts to distort the history of flying, and had recorded in an article I wrote in the "New York Times" on June 22nd, 1914, my protest against the alterations then being made at Hammondsport to the original Langley machine.

I have recently returned from a further investigation in America, and I am now in a position to report to this Society, not only that Lord Northcliffe's statement is fully justified, but that the Hammondsport trials have been inaccurately reported to the Smithsonian Institution. An official report declaring that the Langley machine had been flown at Hammondsport has since been issued by the Smithsonian Institution.

Since the publication of this Smithsonian report, Langley has been widely accepted as the pioneer of aviation, and Langley is now widely credited with having invented and constructed the first man-carrying aeroplane capable of sustained free flight.

The Smithsonian Institution has always attributed the failure of the Langley machine in 1903 to a failure in the launching apparatus, and it has hitherto been generally accepted that the machine was wrecked without having had a fair opportunity to prove whether it was capable of flight. It is easy, therefore, to understand that since the Wrights, who had been working on the same problem, succeeded where Langley had failed, Langley's friends eagerly welcomed the suggestion made ten years later that it might still be possible to prove that Langley's machine was capable of flight. If Langley's machine could be flown, one of the most dramatic events in the history of aviation would be accomplished! Langley and the Wrights had been working concurrently, hundreds of miles apart, for several years, and both had approached the final stage of their independent experiments at the same time. Langley tested his machine a few weeks before the Wrights were ready to test theirs, and the attempts to fly the Langley machine failed. The Wrights, one week after Langley's second attempt, tested theirs and succeeded. Was it merely a mishap which robbed Langley of the credit of being the first to fly, or did he fail because the machine he had built was not capable of flight? It is not surprising, therefore, that when Mr. Glenn Curtiss offered to fly the old Langley machine, Secretary Walcott, who had succeeded Professor Langley as Secretary of the Smithsonian Institution, should have welcomed the opportunity to have Langley's machine tested. It cannot be denied, however, that it was unwise to accept Mr. Curtiss' offer to carry out the tests, because the Curtiss Aeroplane Company had just been adjudged an infringer of the Wright Patent, and Mr. Curtiss obviously might have had other motives than merely the vindication of Langley. It certainly was not proper to appoint Dr. Zahm to represent the Smithsonian Institution, when he was known to have been the technical expert witness for the Curtiss Aeroplane Company in its former suits, and when he was about to represent the Curtiss Company in another infringement suit, in which these tests were to play a most important part. This, however, was the situation, and is verified by the fact that although Dr. Zahm says that the Smithsonian Institution agreed to pay the costs of the experiments, none of the costs apart from the carriage of the machine to Hammondsport have ever been paid by the Institution.

The construction of the Langley machine of 1903 is described in the Langley Memoir of Mechanical Flight, published by the Smithsonian Institution in 1911.

A copy of this work has been presented to the Royal Aeronautical Society, so that it may be used for the purpose of verifying the statements contained in this Paper.

Figs. 1 and 3 of the diagrams in this paper, showing certain features of the Langley machine, are from drawings in the Langley Memoir. The construction of the machine used at Hammondsport is shown in the photographs and in Figs. 2 and 4 of the diagrams accompanying this Paper.

Plates 1 and 3 are from the Langley Memoir of Mechanical Flight.

Plates 8, 11 and 13 are from photographs, in Zahm's official report on the Hammondsport trials, published in the Smithsonian Annual Report of 1915.

Plate 9 is from the Secretary's Report in the same publication.

Plate 12 is from the affidavit of Zahm as a witness for the Curtiss Company in the Wright-Curtiss Patent suit.

Plates 2, 4, 5 and 16 are from photographs which I purchased at the Smithsonian Institution in April, 1921.

Plates 6, 7 and 14 are from photographs by Benner, a photographer at Hammondsport, and were secured in 1915.

Plate 15 is from a photograph taken by Lorin Wright on June 4th, 1915.

Plate 10 is from a photograph taken by myself, June, 1914.

The plates reproduce but a few of the many photographs of the Hammondsport machine which I have examined, and which show the alterations mentioned in this Paper.

Figs. 2 and 4 are sketches, made to scale, showing the features of the Hammondsport machine, corresponding to those shown of the Langley machine, illustrated in Figs. 1 and 3. Figs. 2 and 4 were made from the photographs and from information furnished in the affidavit of Zahm in the Wright-Curtiss Patent suit. Most of the changes from the original Langley machine, shown in Figs. 2 and 4, can be verified by an examination of the photographs here reproduced.

In April, 1914, the original Langley machine, which had collapsed on the two attempts to launch it in 1903, was sent by the Smithsonian Institution to the Curtiss Aviation Field, at Hammondsport, N.Y., and entrusted to Mr. Glenn H. Curtiss. A modified machine was built up at Hammondsport, under the direction of Mr. Curtiss, and under the observation of Dr. Zahm, and flights were then attempted to be made with this Hammondsport machine. An official report, written by Dr. A. F. Zahm, was afterwards issued in 1915 by the Smithsonian Institution, proclaiming that flights had been made at Hammondsport, N.Y., in 1914, by the original Langley machine. (See Annual Report of Smithsonian Institution, 1915.)

This Hammondsport machine was afterwards returned to the Smithsonian Institution at Washington, D.C., and the original portions still remaining were utilised in the reconstruction of a facsimile of the original Langley machine. This reconstructed machine is now exhibited in the U.S. National Museum with the following inscription :—

ORIGINAL LANGLEY FLYING MACHINE, 1903.

> The first man-carrying aeroplane in the history of the world capable of sustained free flight. Invented, built, and tested over the Potomac River by Samuel Pierpont Langley in 1903. Successfully flown at Hammondsport, N.Y., June 2, 1914.

I am here to-day to show members of the Royal Aeronautical Society that both the Smithsonian Report and the inscription on the Langley machine are

misleading and untrue. No attempt was made at Hammondsport to fly the original Langley machine. At Hammondsport fundamental aerodynamic alterations were made to the machine which were not mentioned in the report by Dr. Zahm to the Smithsonian Institution. This Hammondsport machine was then put through so-called flying tests, altered after almost every test, and the tests were reported as flights of the original Langley machine. The Smithsonian Institution was led to believe and falsely proclaim that Langley had succeeded, where in fact Langley knew that he had honourably failed.

I fully appreciate the serious responsibility I am undertaking in making these statements, but I am confident that when you have heard the evidence which follows in my paper, which is only a part of the evidence in my possession, you will recognise that an undesirable fiction has been imposed upon the Smithsonian Institution and on an unsuspecting public.

It is of the greatest importance that this Society, in its position as the oldest aeronautical body in the world, shall have its records truthfully maintained. Already Professor Bairstow has, in his Wilbur Wright Lecture in 1919, been misled by the Smithsonian Report into telling this Society that a flight had been made during the war period by the man-carrying aeroplane which Langley designed and made; and as recently as this year Mr. Vivian and Lieutenant-Colonel Lockwood Marsh, in their otherwise excellent "History of Aeronautics," state that it has been proved in these later years that the machine which Langley launched in 1903 was fully capable of sustained flight, and that but for the two accidents, the honour which fell to the Wright Brothers would have been secured by Samuel Pierpont Langley. It is no disparagement of Professor Bairstow, Mr. Vivian, nor of the genial Secretary of the Royal Aeronautical Society, to say that they believed the Smithsonian Report, but it is all-important that they in common with all our other members should learn the truth, and so be saved in future from passing on fiction as truth to those who look to them for facts.

As many members may not be acquainted with the original Langley machine I will briefly describe the main features of its construction and operation, and also the attempts which were made by Langley to fly this machine in 1903.

Photographs, Plates 1 and 2, are a side view and front view respectively of the Langley machine on the houseboat on the Potomac River in 1903, and Fig. 1 is a scale side view diagram of the same Langley machine, showing the more important members and their arrangement.

WW the wings set at an angle of 10 degrees with frames F. As shown in Plate 2, the wings had a dihedral angle to provide lateral balance.

SS the central wing spars.

S^1S^1 the forward wing spars.

C the pilot's car.

M the Langley 5-cylinder radial motor.

P one of the two propellers (the other being exactly behind cannot be seen in the diagram).

K a large fixed keel surface.

V a vane rudder composed of two planes separated at the rear, thus forming a wedge. It is hinged to the keel surface K and made operable from side to side for the purpose of steering to right or to left.

R a large dart-shaped tail, the horizontal surface of which is set at a negative angle of six degrees with the main frame, forming a Penaud tail. This tail R was attached to the frame so that it could be adjusted up and down to different angles, but could not be turned from side to side for steering.

GG single guy posts for bracing each set of wings. The part of each guy post below the main frame F was of wood, having a maximum diameter of

1¼ins. The part above the main frame was of ¾in. steel tube. From the top and bottom of the guy post G, wires run to the spars S and S^1, the guy post being midway between the two spars. I call particular attention to the location of these guy posts, which was only 28 per cent. back of the front edge of the wing, because I believe it will help to explain the failures which happened on both occasions when attempts were made to fly the machine in 1903.

The Langley machine above described was launched from a houseboat on the Potomac River. The machine was fastened to a car which ran on a track on the top of the boat. Besides the thrust of the propellers, a powerful spring was used to assist in giving the machine the necessary initial speed. In the first test on October 7th, 1903, the machine after leaving the launching car dived, as is shown in Plate 3, and plunged into the water a short distance in front of the houseboat. At the time there was no thought that the launching apparatus had not performed properly, as is indicated by the statements made by Mr. Reed, who observed the launching from the houseboat, and by Mr. Manly, who was in the machine. Mr. Reed stated that—

> "Immediately upon my releasing the machine the launching car which carried it dashed down the track, and it appeared at first that when the car reached the end of its track the machine had been successfully launched." (Reed Affidavit, p. 17),

and Mr. Manly, immediately upon his return to the houseboat after plunging into the water, made the following statement to the Associated Press:—

> "It must be understood that the test to-day was entirely an experiment, and the first of its kind ever made. The experiment was unsuccessful. The balancing, upon which depends the success of a flight, was based upon the tests of the models and proved to be incorrect, but only an actual trial of the full-size machine itself could determine this. My confidence in the future success of the work is unchanged. I can give you no further information. I shall make a formal report to Secretary Langley." (Langley Memoir, p. 266.)

It will be observed that Reed thought "the machine had been successfully launched," and that Manly did not remember at that time anything in the launching to even excite suspicion that the launching apparatus was in any wise at fault.

Plates Nos. 3 and 4 are from photographs taken simultaneously just after the machine had left the launching ways. Plate No. 3 shows the machine diving towards the water, and Plate No. 4 shows a view taken from the houseboat looking at the under side of the machine as it dived. The forward wings, it will be observed, are bent out of shape, the back edges being turned upward until the inner portions of these wings have come in contact with the projecting propeller frames which normally were about 18ins. above. The outer portions of the wings, not being restrained by this frame-work, are bent up still farther, as Plate No. 4 clearly shows. It also will be observed that the rear wings are likewise distorted, though to a less degree.

After the machine had been recovered from the water it was discovered that the lower guy post G, of the front wings, was bent backward, and that the front end of the metal frame-work was bent downward. (Langley Memoir, p. 267.) It was also found that the metal cap, which held the front guy post from rising during the launching, but did not restrain it from slipping out forward, had been stretched out of shape. Since this cap was of thin metal, and had to hold the entire lift of the wings during launching, it is not surprising that it was "stretched out of shape." From the fact that the guy post was bent backward it was assumed that in the launching this metal cap had failed to allow the free movement forward of the guy post as it had been designed to do. Some years

later, in describing this launching, Mr. Manly, in explaining that the launching apparatus had failed to properly release the machine, states that he felt a shock when the machine reached the end of the track. But as he made no mention of it at the time it may be fair to assume that when some years later he thought he remembered a shock, what he really remembered was the idea formed after he had learned of the bending of the post. It seems reasonable that his memory immediately after the flight would be more reliable than it was after a lapse of several years.

On December 8th, 1903, after repairs had been made, a second attempt was made to launch the machine.

> "After starting up the engine and bringing it to full speed, the writer (Manly) gave the signal for the machine to be released, and it started quietly, but at a rapidly accelerated pace, down the launching track. Exactly what happened, either just before or just as the aeroplane reached the end of the track, it has been impossible to determine, as all the workmen and visitors had gone to their stations on the various auxiliary boats, except the two workmen (Reed and McDonald) who had been retained on top of the boat to assist in the launching. It had grown so dark that the cameras of Mr. Smillie, the official photographer, were unable to get any impression when he used them, owing to the extreme rapidity of the shutters with which they were equipped. Fortunately, one photograph of the machine while still in the air was secured, which shows the result of what had occurred in the launching and before any further damage had been caused by its coming down into the water, but the all-important question as to just what caused the accident which did occur remains to a certain extent a mystery." (Langley Memoir, p. 271.)

I here show in Plate No. 5 the photograph just referred to. The upper side of the forward wings of the machine is seen at the top of the photograph and the crumpled rear wings below. It will be noticed that the spars of the right forward wing are broken and that the front end of the metal frame-work is again bent down just as it was in the former trial. There has never been any claim that this forward part caught in the launching ways in this attempt. Mr. Manly, who had these wings in front of him during the launching, did not observe that they were being broken by any entanglement during the launching. The rear wings and the Penaud tail broke during the launching.

> "Mr. Reed, the foreman, who (according to Manly) was qualified to observe accurately, not only through his having worked continuously for many years on the machines, but also from his having witnessed the numerous tests of the models, states that from his position near the rear end of the launching track he noticed that at a point about ten feet before the machine reached the end of the track the Penaud tail seemed to have dropped at the rear end in some inexplicable way so that it was dragging against the cross-pieces of the track, and that at the next instant, when the car reached the end of the track, he saw the machine continue onward, but the rudder and whole rear portion of the frame and the wings seemed to be dragging on the launching car." (Langley Memoir, p. 272.)

On this second attempt to launch the machine, no contention has been made that it was the launching apparatus which failed, but it is conceded that the trouble commenced with the failure of a portion of the machine, namely, the falling of the Penaud tail, which apparently was not supported strongly enough to withstand the downward pressure resulting from the fact that it was mounted on the machine at a negative angle. It will be noticed in the photographs and the diagrams that this tail rudder was set at a negative angle.

That the launching apparatus up to this time had been reliable is shown

by Mr. Langley's own statement in his annual report to the Smithsonian for the year 1904:—

> "A new launching apparatus following the general plan of the former overhead one, but with the track underneath it, was built for the models, and it was used most successfully in these experiments, more than a dozen flights in succession being made with it, while in every case it worked without delay or accident. As soon as these tests with the models on this underneath launching apparatus were completed, that for the large machine was built as an exact duplicate, except for the enlargement, and with some natural confidence that what had worked so perfectly on a small scale would work fairly on a large one . . . . .. it was felt that if this apparatus were exactly similar to the smaller one, it would be the one appliance least likely to mar the experiments." (pp. 115 and 119.)

It is not reasonable to attribute the collapse of the wings to a failure of the launching mechanism, a mechanism which Mr. Langley states had been used most successfully in more than a dozen launchings of models, when there were several perfectly good reasons why the wings would collapse under any conditions of launching.

The wings of the Langley machine had but a slight factor of safety as was shown in the sand tests of the wings as described on page 203 of the Langley Memoir. When a sand load of only 20 per cent. above the flying stress was imposed, most of the ribs were bent from 12 to 13 inches out of shape. Langley could not make the wings stronger, because he considered the machine already as heavy as it could be, if free flight was to be attained. And it is clearly impossible to launch such a machine using an outside force to give it initial momentum without subjecting it to greater stresses than it would be subjected to in normal flight. On the other hand the machine could not carry its own launching device because this slight extra weight would prevent it from flying at all. It should be remembered that the machine had been designed and tested with a view of standing the stresses of flight only. Being rigidly held down to the carriage in launching, it was forcibly prevented from rising into the air when it had attained the necessary speed for flight. But the stress on the wings of the machine so bound down increased as the square of the speed of the machine with reference to the air, and the wings therefore may have been subjected to excessive pressures before the machine was released at the end of the track.

Earlier in this Paper I called particular attention to the position of the guy post G (Fig. 1), which is 28 per cent. from the front edge of the wings. According to the Jöessel formula, the formula generally used at the time to calculate the centre of pressure on an aeroplane surface, the centre of pressure at 10 degrees incidence was a little over 25 per cent. back from the front edge of a plane. Mr. Langley had made no measurements to locate the centre of pressure at small angles. In this case it will be noticed that Langley placed the guy posts just about where any engineer would have placed them if the centre of pressure were believed to be 25 per cent. from the front edge of the wings. But the centre of pressure with change of angle on a curved surface travels at all flying angles in the opposite direction from that on a plane. Langley's machine was designed without taking this fact into consideration. This vital law was first published to the world in the Paper read by Wilbur Wright before the Western Society of Engineers on September 18th, 1901, and it appears that Langley did not profit by this information. Otherwise he would not have placed the guy posts so far forward as in the position shown in the diagram in Fig. 1.

The centre of pressure on the Langley wings would have been about 37 per cent. back from the front edge while being launched at 10 degrees angle of incidence. But at smaller angles of incidence, such as it would have taken im-

mediately upon being released, the centre of pressure would have moved still farther back. The turning-up of the rear edges of the wings and the bending-back of the guy post are but the natural consequence of placing the trussing too far forward of the centre of pressure and of the trussing not being strong enough to withstand this unguarded stress. The breakage of the wings in both tests in 1903 was due to faulty design, and not to a failure of a part of the launching mechanism to perform as it was designed to perform.

I think I have said sufficient here to show the technical members of the Society that the failure of the original Langley machine was due to the collapse of the wings owing to their frailty and to bad engineering in placing the guy posts so far forward of the centre of pressure. The fact that the wings were subject to much greater stress during the time the machine was held down to the launching car, than it would have experienced if it had been free to rise, is surely sufficient reason for the failure of the machine, without assuming the additional accident of the guy posts catching in the launching apparatus. I will not, therefore, labour this point, especially as I am now going to show, when comparing the Langley machine with the Hammondsport machine, that Dr. Zahm and Mr. Curtiss apparently knew of these fatal mistakes in the design of the Langley machine, and attempted to correct them when building the Hammondsport machine.

After the original Langley machine had arrived at Hammondsport, in April, 1914, Dr. Zahm and Mr. Curtiss proceeded to build up the Hammondsport machine partly from the original Langley machine and partly from new parts. (Zahm Affidavit, p. 4.)

Among the many changes existing in the Hammondsport machine at the time of its early trials in May and June, 1914, I will briefly mention the following:—

1. New wings were constructed at Hammondsport in which all of that portion in front of the forward spar of the Langley machine (see Fig. 1 of the diagram) was entirely omitted, and thus the forward spar S^1 formed the leading edge of the Hammondsport wings (see Fig. 2 of diagram and Plates 8, 9 and 14). The camber of the Langley wings was 1 in 12, while that of the Hammondsport machine was about 1 in 18. The area of the Langley wings was 1,040 sq. ft., that of the Hammondsport wings about 990 sq. ft. The Hammondsport wings also had a slightly different aspect ratio from that of the Langley machine. These changes, as is well-known to all aeronautic engineers, produce a wing of entirely different aerodynamic properties from the original Langley wing.

2. In the original Langley machine the wings were stayed by wires to single guy posts GG, projecting above and below the central frame F. The part of the post above the central frame was replaced by two very much larger posts, having about twice the height of the original guy posts and forming an inverted V over the central frame. The single guy post below the central frame in the Langley machine was replaced by four much heavier posts. (See Plates 6, 7, 8, 9, 10, 11, 12, 13, 14 and 15.)

3. The guy wires at Hammondsport were attached to the spars at different points than in the Langley machine, the advisability of which change was made apparent by the breaks in the spars in 1903. (Compare Figs. 3 and 4.) These changes can be seen in some of the original photographs, but are not so clear in the plates.

4. This whole system of trussing, which replaced the guy posts used by Langley, was moved 30ins. farther back, so as to be near the normal centre of pressure on the wings (Figs. 1 and 2, and Plates 7, 8, 9, 12 and 14). I have already called attention to the seriousness of Langley's lack of knowledge in placing these guy posts so far forward.

5. The middle spar of each front wing was strengthened by an additional spar E underneath the ribs and extending outward for about two-thirds of their length.

These middle spars, not reinforced, had collapsed in the tests of the Langley machine in 1903. (Fig. 4.)

6. The wings were further strengthened by the under truss work G G G G and E^1 E^1, diagonally braced, rigidly supporting the wings to about a quarter of their length out from the central frame (Fig. 4 and Plates 6, 7, 10 and 11). This truss work has been referred to by Dr. Zahm as being for the support of the widely separated front floats, but as this extended truss work was also employed under the rear wings, where only central floats were employed, it cannot be correct to say that this extended truss work was for the sole purpose of carrying widely separated floats. This can be clearly seen in practically all of the photographs shown of the Hammondsport machine.

7. The ribs of the Hammondsport machine were made heavier than the box construction of the Langley machine, and were stronger.

8. Hydroplane floats H H, unknown in the day of Langley and developed between the years 1909 and 1914, were substituted for Langley's original method of launching (Zahm Affidavit, p. 5).

9. The large fixed keel vertical surface (K, Fig. 1) situated below the frame in the Langley machine was entirely omitted in the Hammondsport machine. (Plates 7, 8, 9, 10, 12, 14 and 15.)

10. The small split vane steering rudder (V, Fig. 1) of the Langley machine was replaced with a single rudder (V, Fig. 2) of about one and a half times the area. The small vane rudder of the Langley machine was adjusted from a self-locking hand-wheel, and was intended to steer the machine slowly to right or to left (Langley Memoir, pp. 214, 216), while the large single surface rudder in the Hammondsport machine was connected part of the time to the regular Curtiss wheel, part of the time to the Curtiss yoke, and was used for maintaining lateral balance (Zahm Affidavit, p. 6; Zahm Report, p. 219), a system of control universally used to-day but entirely unknown to Langley.

11. The Penaud tail in the Hammondsport machine, instead of being merely adjustable up and down by a self-locking hand-wheel, as arranged by Langley (Langley Memoir, p. 216), was coupled to a regular Curtiss steering post in the Hammondsport machine (Zahm Affidavit, p. 5 and Plate 7), and was attached to an upstanding bracket, instead of to a depending bracket, as used by Langley, which gave it a position about 20ins. higher than in the Langley machine.

12. The original carburettor on the Langley engine was changed for one of modern type at Hammondsport. (Butman in Aviation, November 15th, 1917.)

13. The radiator employed by Langley was changed in the Hammondsport machine for a radiator of modern type. (Plates 6, 7 and 11.)

14. The forward corners of the original Langley propellers were cut off, after the manner of the early Wright propellers (see Plates 6, 7 and 8).

15. The Penaud tail rudder R on the Hammondsport machine was made turnable about a vertical axis (Zahm Affidavit, p. 7), a movement not intended by Langley in the machine of 1903. (Langley Memoir, p. 214.) This tail rudder was connected to a regular Curtiss steering wheel.

Although the machine was altered as above described, Dr. Zahm tells us in the affidavit which he afterwards made that he had frequently seen the original Langley machine in the Smithsonian Institution, and he was thoroughly familiar with its construction and operation; and he avers that

> "The machine . . . was the same machine in construction and operation as the original structure. The frame was the same; the engine was the same; the horizontal and vertical rudder located at the rear was the same; the vertical rudder under the machine was substantially the same; the propellers were the same and the wings were identical in construction

> with the original machine, except, as I have heretofore stated, they were perhaps a little more roughly built and a little heavier." (Zahm Affidavit, p. 5.)

This statement does not accord with the facts as I have just shown them—most of which facts are clearly corroborated by the photographs here reproduced.

After making the aforementioned alterations, Dr. Zahm tells us in his official report to the Smithsonian Institution that the machine "rose in level poise, soared gracefully for 150 feet, and landed softly on the water." I was at Hammondsport in 1914 within two weeks after the last tests were made in which the Langley motor was used. I could not find any photos among the many photos on sale to show the machine in flight. I was told, however, that the machine did actually make short hops, due to its initial speed, and I have no reason to doubt that this was true. This, however, does not prove that the machine was capable of "sustained free flight," since it is well known that a machine incapable of sustained flight may make hops.

Several so-called flights are stated to have been made with this Hammondsport machine, which Dr. Zahm refers to as "the Langley aeroplane, kept as nearly as possible in its original condition," but they were obviously only hops over the surface of the water, and in none was "sustained free flight" attained, because, as Dr. Zahm states in the Affidavit which he made some time later, "it was apparent that owing to the great weight which had been given to the structure by the adding of the floats, it was necessary to increase the propeller thrust." (Zahm Affidavit, p. 8.)

Dr. Zahm here admits that the machine was not really in flight, because if it had been flying more propeller thrust would not be necessary in order to make it fly.

From the evidence that I have already brought to your attention, I submit that two facts are clearly proved:—

(*a*) The Langley machine was not capable of sustained free flight.

(*b*) The Langley machine was not successfully flown at Hammondsport, New York, on June 2nd, 1914.

The inscription on the Langley machine should therefore be changed to accord with the facts.

It having been shown in these early tests that it was necessary to increase the propeller thrust before a real flight could be made, the Langley engine and propellers were removed from the Hammondsport machine and a modern engine with a modern propeller were installed. This entailed a number of further alterations, a part of which I will mention.

16. The Langley engine, which in the Langley Memoir is said to have given 52.3 h.p. on the bench for ten hours, was now removed, and a Curtiss 80-100 h.p. motor was substituted (Zahm Affidavit, p. 8) and placed about 3½ft. farther forward on the machine (Fig. 2, and Plates 11 and 14).

17. The Langley modified twin propellers were removed and a modern tractor propeller, designed with knowledge acquired since Langley's day, was mounted in front of the machine (Zahm Affidavit, p. 8), about 16ft. forward of the location of the Langley propellers (Fig. 2, and Plates 11 and 12).

18. The pilot's car was now removed and the pilot's seat was placed about 14ft. farther back and about 3ft. higher than the seat in the Langley machine (Zahm Affidavit, p. 9, Fig. 2, and Plates 12, 13 and 14).

It was only after these further alterations and with the more powerful motor that hops of more than five seconds' duration were made. Dr. Zahm in the Smithsonian Report, p.221, in describing these later alleged flights on October 1st, 1914, says:—

> "Hovering within 30ft. of the water, and without material loss of speed,

it made in quick succession flights of the following durations . . . 20 seconds, 20 seconds, 65 seconds, 20 seconds, 40 seconds, 45 seconds. . . .

"Apparently the machine could have flown much higher, and thus avoided touching the water during the lulls in the breeze; but higher flying did not seem advisable with the frail trussing of wings designed to carry 830lbs. instead of the 1,520lbs. actual weight."

Dr. Zahm suggests that there was loss of speed and that the machine touched the water during the lulls in the breeze. We may take it that the machine did not fly but that it made long hops during the gusts and came to the surface of the water with each lull in the wind.

Dr. Zahm was perfectly well aware at the time he made this statement, that the frail trussing of the wings designed by Langley, was not used on the Hammondsport machine. The trussing of the Hammondsport wings was made under Dr. Zahm's observation, and he knew when he made his report to the Smithsonian Institution that the trussing of the wings was not the Langley trussing designed by Langley to carry 830lbs. We know that Langley's wing trussing was frail. That was the reason Dr. Zahm and Mr. Curtiss did not adopt it in building up the Hammondsport machine.

It is interesting to know that on June 4th, 1915, more than a year after the so-called flight of June 2nd, 1914, attempts were still being made to fly the Hammondsport machine. The inverted V-frame over the rear wings was removed and the upper portion of the original Langley guy post was reinstated. Plate No. 15 is from a photo taken on June 4th, 1915, and shows this reinstatement. The following day, at about 10 o'clock in the morning, the machine was taken out and an attempt was made to fly it. After a run of several hundred feet, and before the machine had lifted from the water, the rear wings collapsed as they had done in Langley's day. So far as I am aware no further attempt was ever made to show that the Hammondsport machine was capable of flight. I am sorry not to have a photo of this wrecked machine to show you. Photographs were made of the wreck, but the films were taken from the photographer by the men in charge of the experiments. When the photographer protested that he had been given permission the day before to take photographs of the machine, he was told that while that was true, no photographs of the wrecked machine could be permitted on account of "legal complications."

SUMMARY.

It is untrue to say that Langley's machine of 1903 ever has flown or ever could fly. In both trials in 1903 the wings collapsed through faults in design of the machine, and not from any failure in the launching mechanism.

The machine used at Hammondsport in 1914 differed from the original Langley machine in many important respects.

The wings were of different area, different camber and different aspect ratio.

The system of wing trussing, which in the Langley machine had failed, was completely changed at Hammondsport.

The large keel surface of the Langley machine was altogether omitted.

The Langley system of launching was abandoned, and a system developed after his death was used in its place.

The original Langley propellers were modified and afterwards superseded by a modern propeller, based on knowledge not possessed by Langley.

A system of lateral control unknown to Langley was added. The dihedral angle of the wings on which Langley relied entirely for maintaining lateral balance was supplemented in the Hammondsport machine by the action of a rudder of increased size used as an aileron.

The steering wheel, post and shoulder yoke of a modern Curtiss machine were installed complete in the Hammondsport machine.

The original Langley engine of 52 h.p. was at first modified and afterwards superseded by a modern Curtiss motor of 80-100 h.p.

At first it was necessary to change the machine to carry the engine, and then it was necessary to change the engine to carry the machine. Finally there was neither the original Langley engine nor the original Langley machine.

The remains of the Langley machine were at last returned to the Smithsonian Institution, and were entrusted to Mr. Reed for restoration to the original form of 1903. Mr. Reed did his work well, for when I saw the rebuilt Langley in the National Museum last April, it was very much like Langley built it. The wings had their leading edges restored, thus bringing them back to their former camber and area; the wings were stayed to the old guy posts, which were set forward again to their original but ineffective positions; the Langley propellers were restored; the pilot's car was again under the forward part of the frame; the Curtiss control gear had been removed. In fact, the whole machine had lost all appearance of having been out on an indiscreet adventure. (Refer to Plate No. 16.)

The present paper, however, does not deal with Langley's work except so far as is necessary in order to disprove the wild assertions made by pretended friends in order to build up for their own ends a credit for Langley which could not be enduring, a credit which Langley would be the first to repudiate were he here to do so. No fraud can long endure when so much evidence is on record. If it had not been my privilege to bring these facts before you, some other inquirer would have dug up the evidence at some later time and done the service to Langley I have now done in separating his upright life from association with anything which is not strictly true or honourable.

DISCUSSION.

Colonel A. Ogilvie said he had not much to say about this question, but he would like to pay a tribute to the lecturer himself and to say how much they who knew him intimately respected him for the efforts he had made in the vindication of the Wrights in Europe, and particularly in this country. It was not too much to say that if the Wrights had not had a man of his calibre to defend them from the many attacks that had been made over here, their name would not be so widely respected as it was. As to the actual substance of the lecture, he thought Mr. Brewer had proved his point very clearly, and to anyone who was at all accustomed to aeroplane construction or experiment it was perfectly clear that the original machine would have broken, as it actually did break, and that the altered Hammondsport machine was quite different.

Mr. F. Handley Page said he felt in a little quandary in discussing this paper, as he happened to know the parties on both sides, having this year had the pleasure of staying with Mr. Orville Wright and also of having dined with Dr. Zahm. In addition to that, his own Company had had legal proceedings under the Wright patent in America. When one came to express an opinion as to what were the rights or wrongs of the case, it was rather difficult to be what he might call neutral. There were so many points on Langley's original machine which differed from his experimental work that one rather wondered whether there was some experimental laboratory work unpublished, work possibly carried out after that already published and before the tests on the actual full-size machine. He did not know whether Mr. Griffith Brewer could inform them further on the point. All Langley's original experiments were carried out with

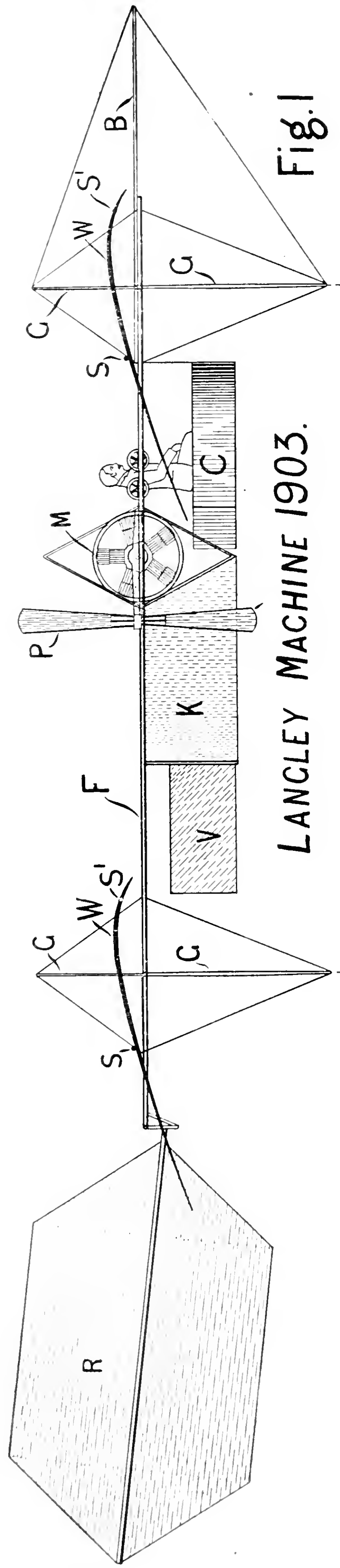


Fig. 1
LANGLEY MACHINE 1903.

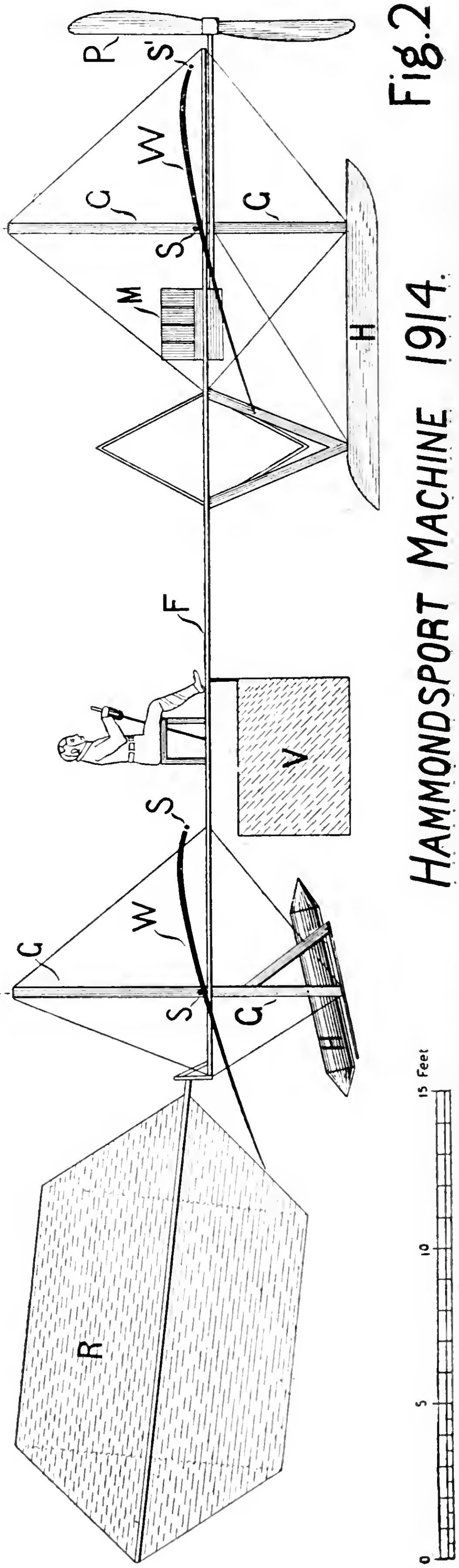


Fig. 2
HAMMONDSPORT MACHINE 1914.

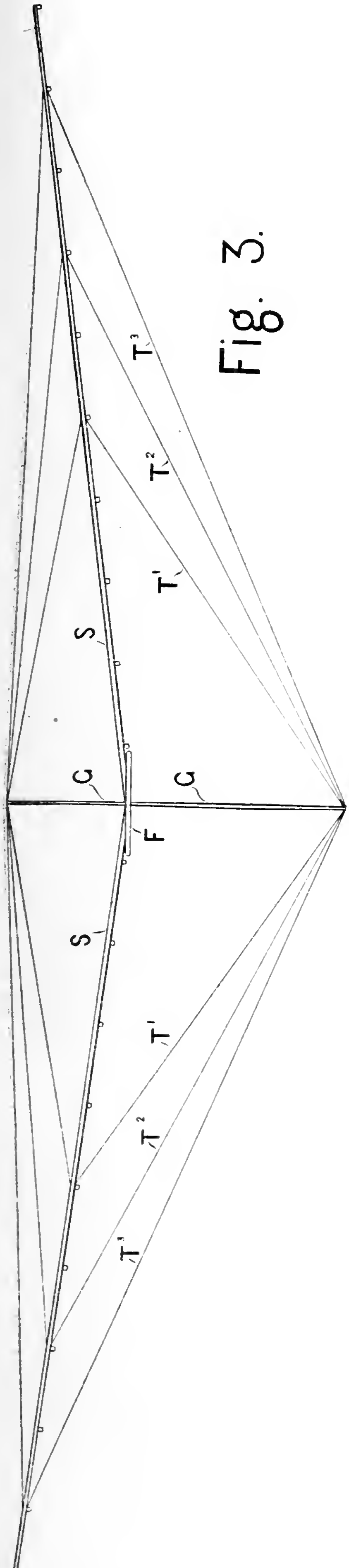


Fig. 3.

LANGLEY WING TRUSSING 1903.

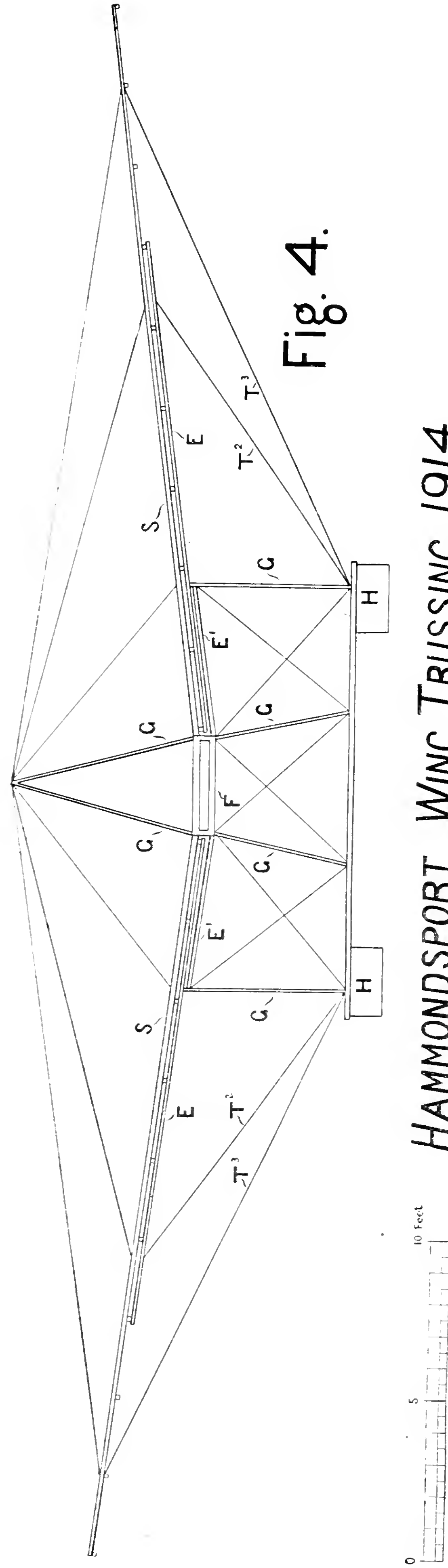
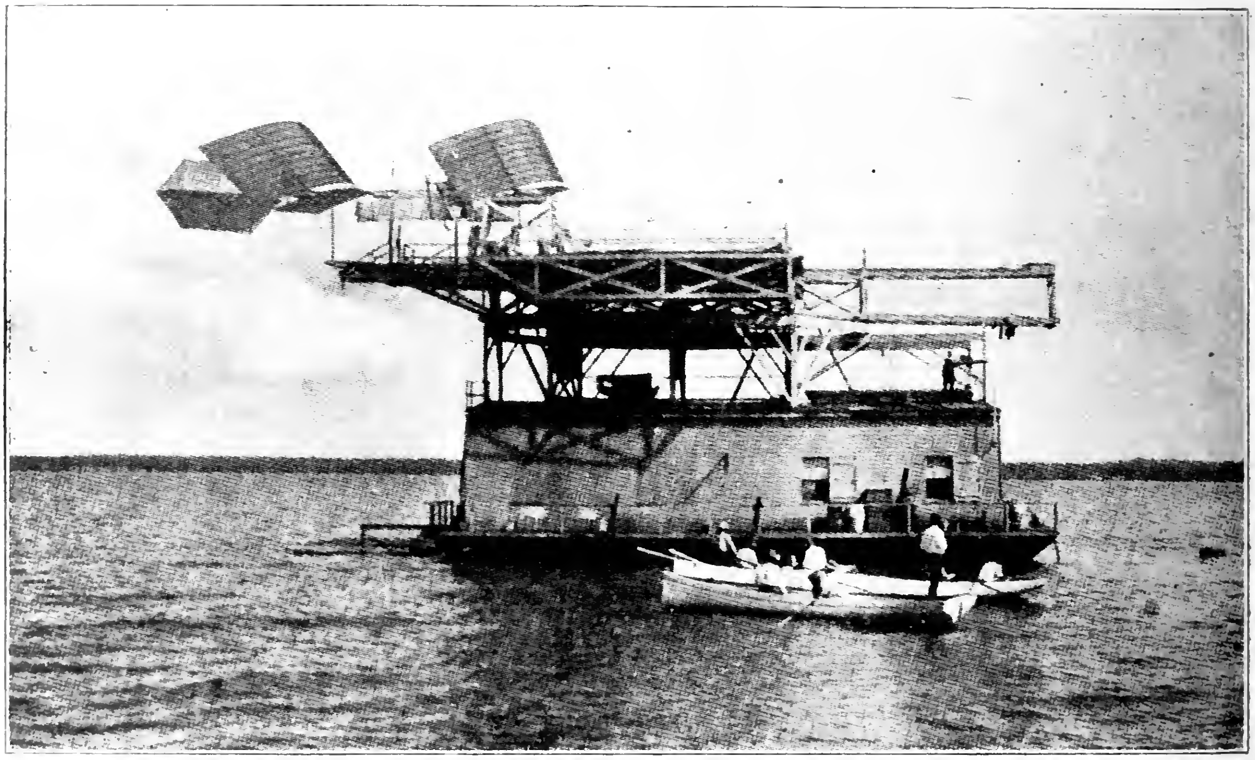


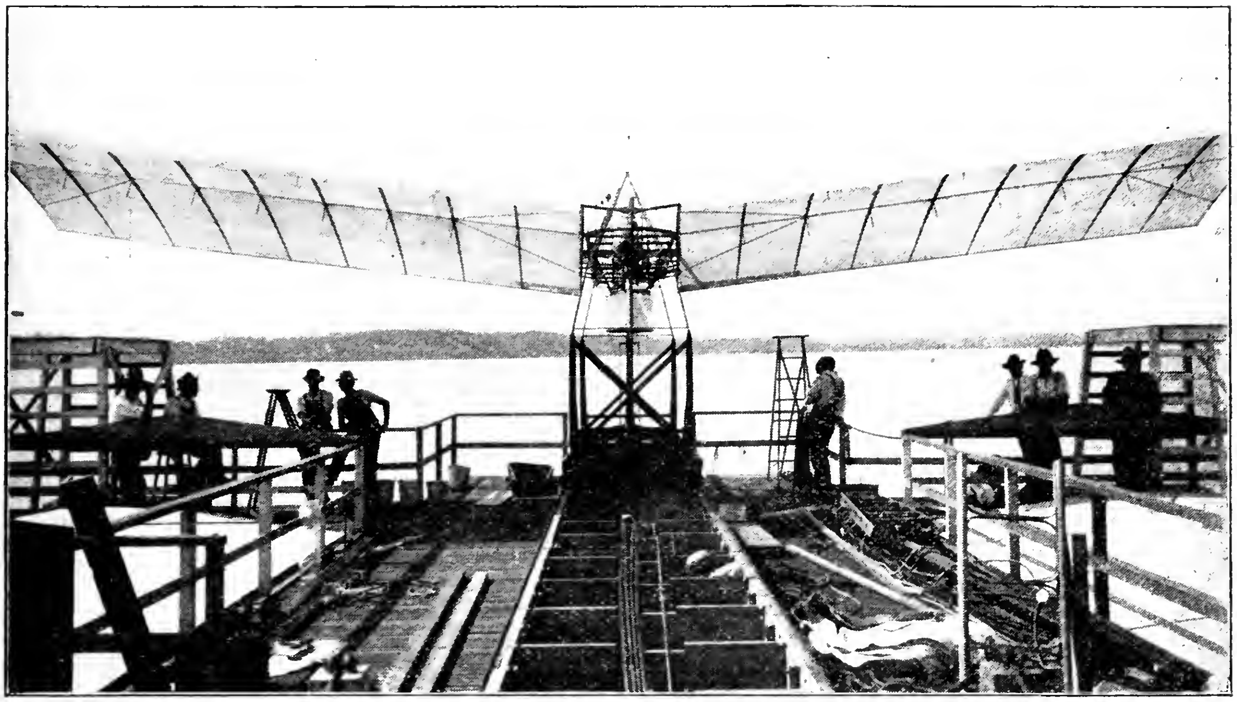
Fig. 4.

HAMMONDSPORT WING TRUSSING 1914.



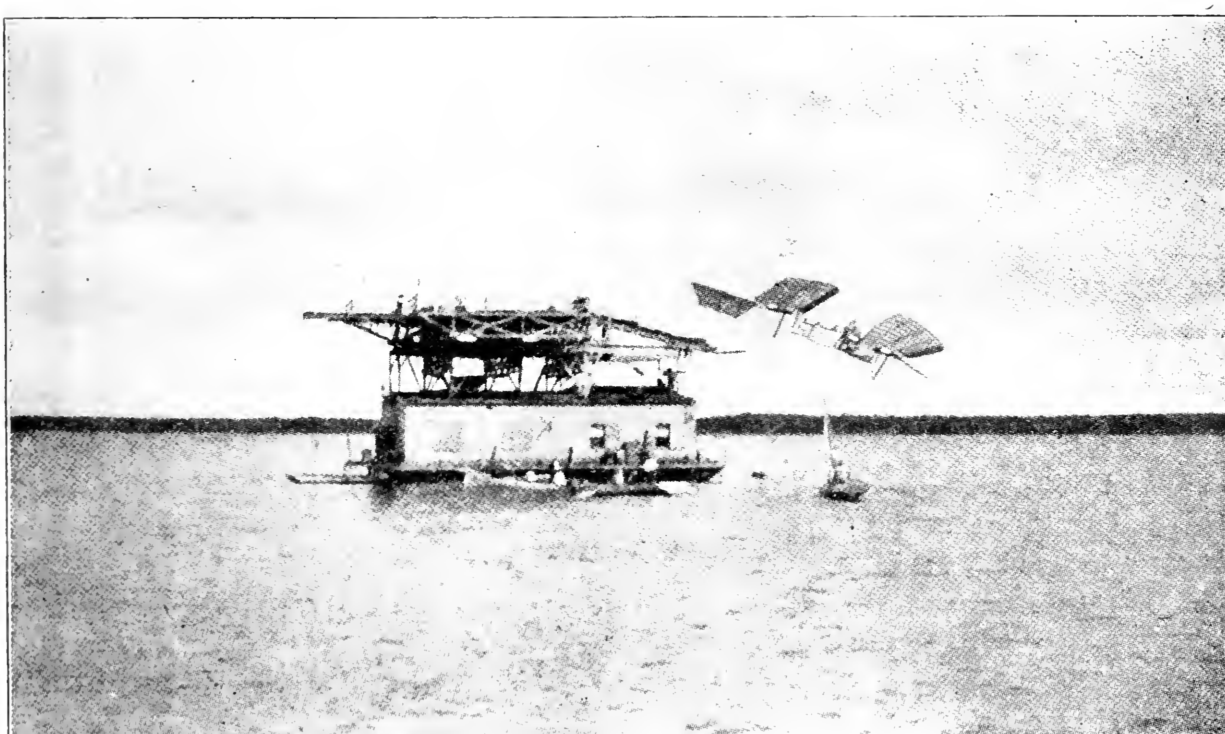
(Photo, Langley Memoir.)

PLATE I.—Langley Machine on houseboat, Potomac River.



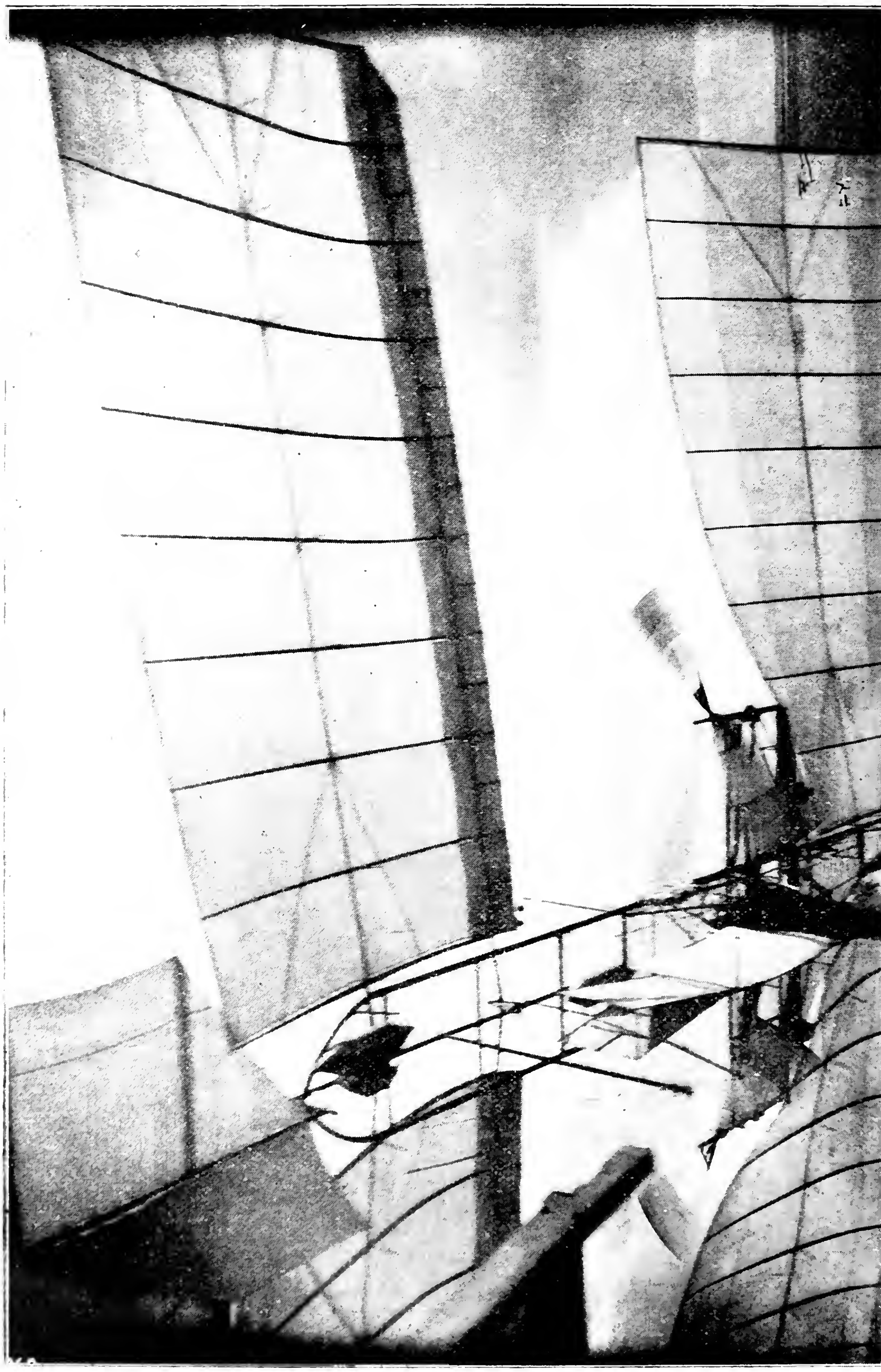
(Photo, purchased April, 1921, Smithsonian Institution.)

PLATE 2.—Langley Machine on launching carriage.



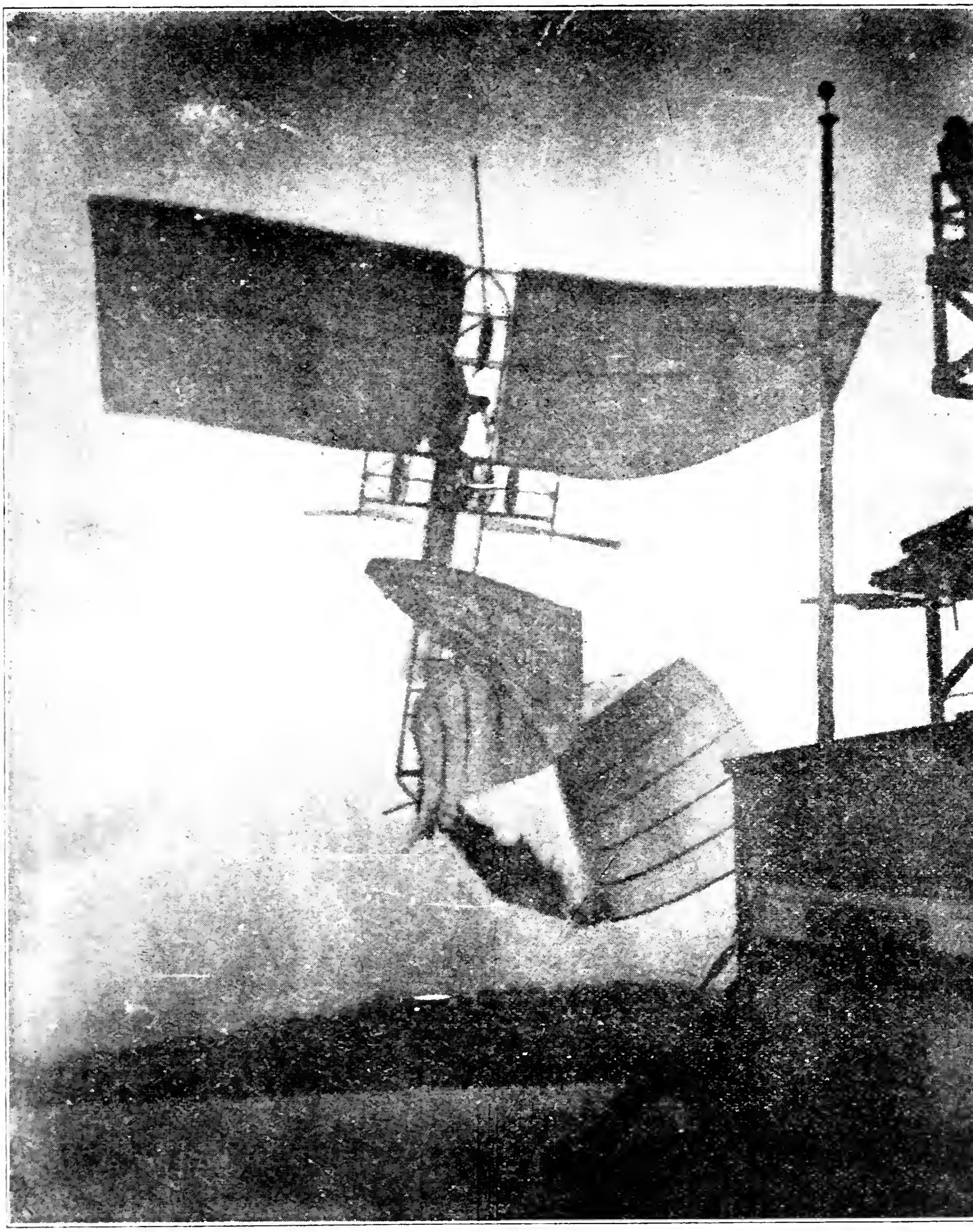
(Photo, Langley Memoir.)

PLATE 3.—Langley Machine falling from launching track into Potomac, 7th October, 1903.



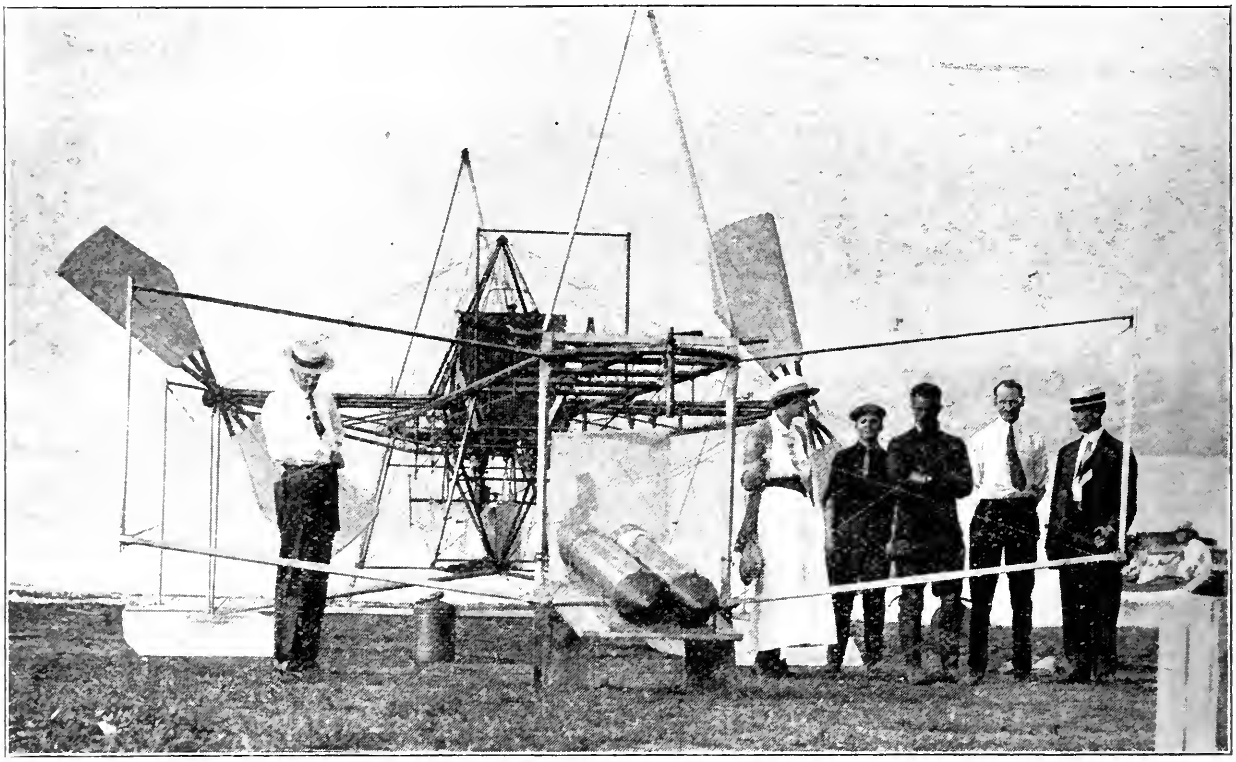
(Photo, purchased April, 1921, Smithsonian Institution.)

PLATE 4.—Langley Machine viewed from below, front wings twisted and bent against framework.



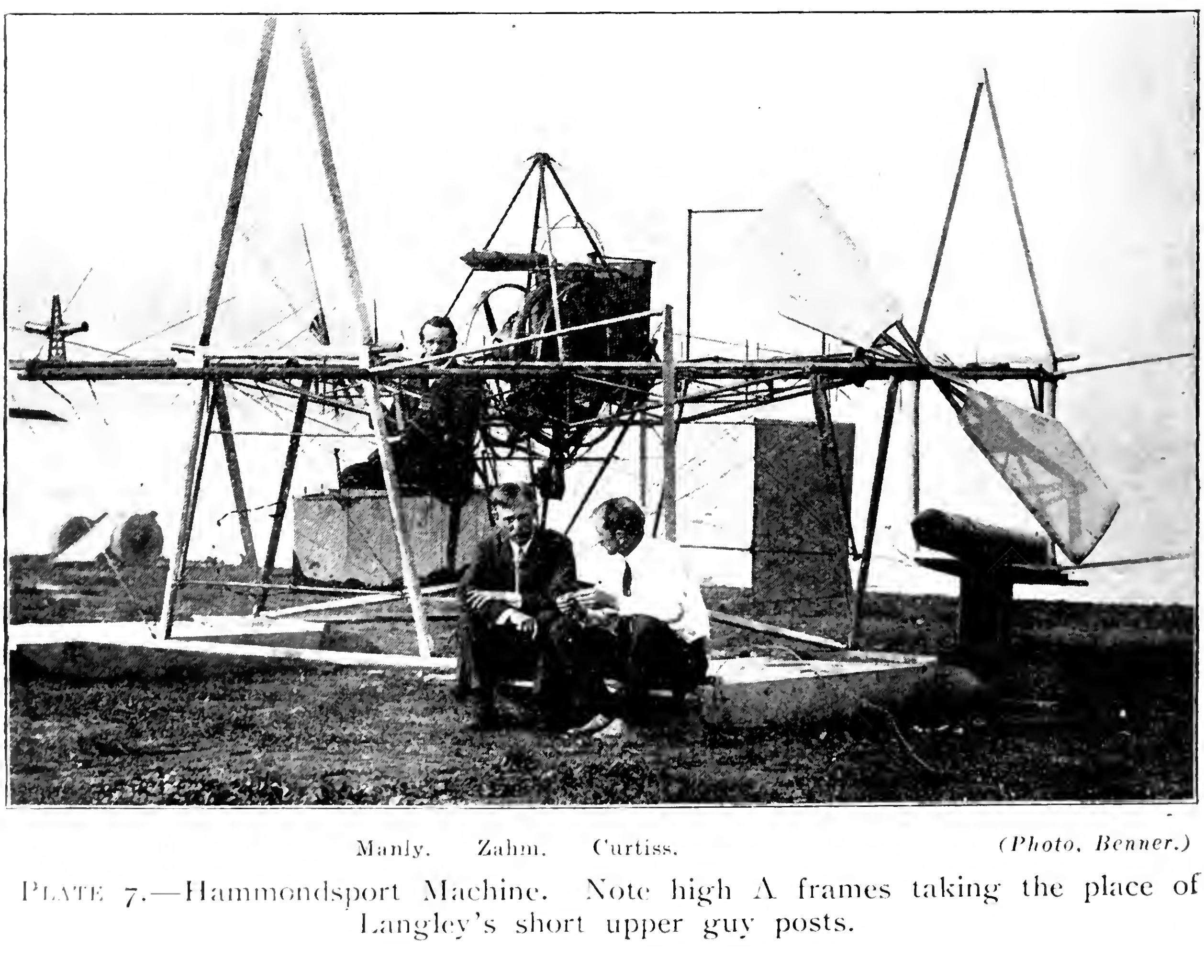
(Photo, purchased April, 1921, Smithsonian Institution.)

PLATE 5.—Langley Machine falling from launching apparatus, 8th December 1903, into Potomac. Note front wings distorted and spars broken, central frame bent.



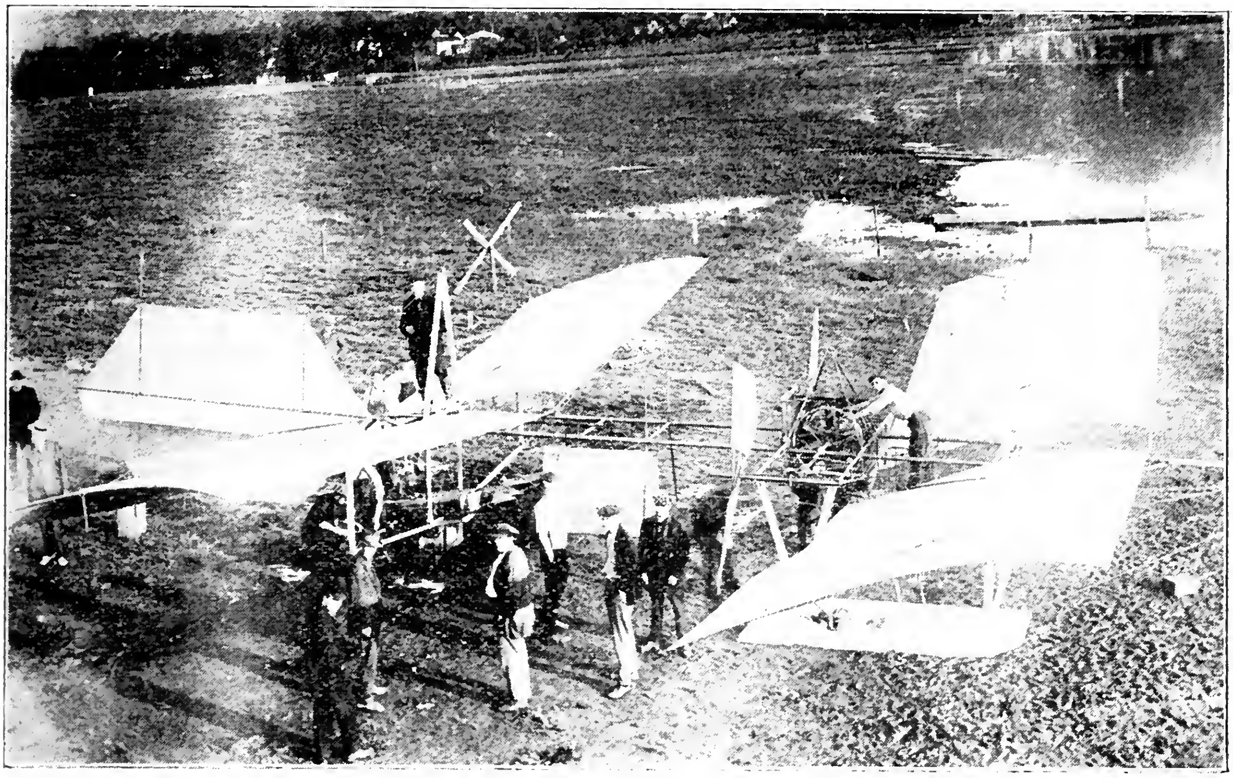
Dr. Walcott. Miss Walcott. Mr. Curtiss. Dr. Zahm.
(*Photo, Benner.*)

PLATE 6.—Hammondsport Machine with wings removed. Note additional spars and trussing for supporting wings.



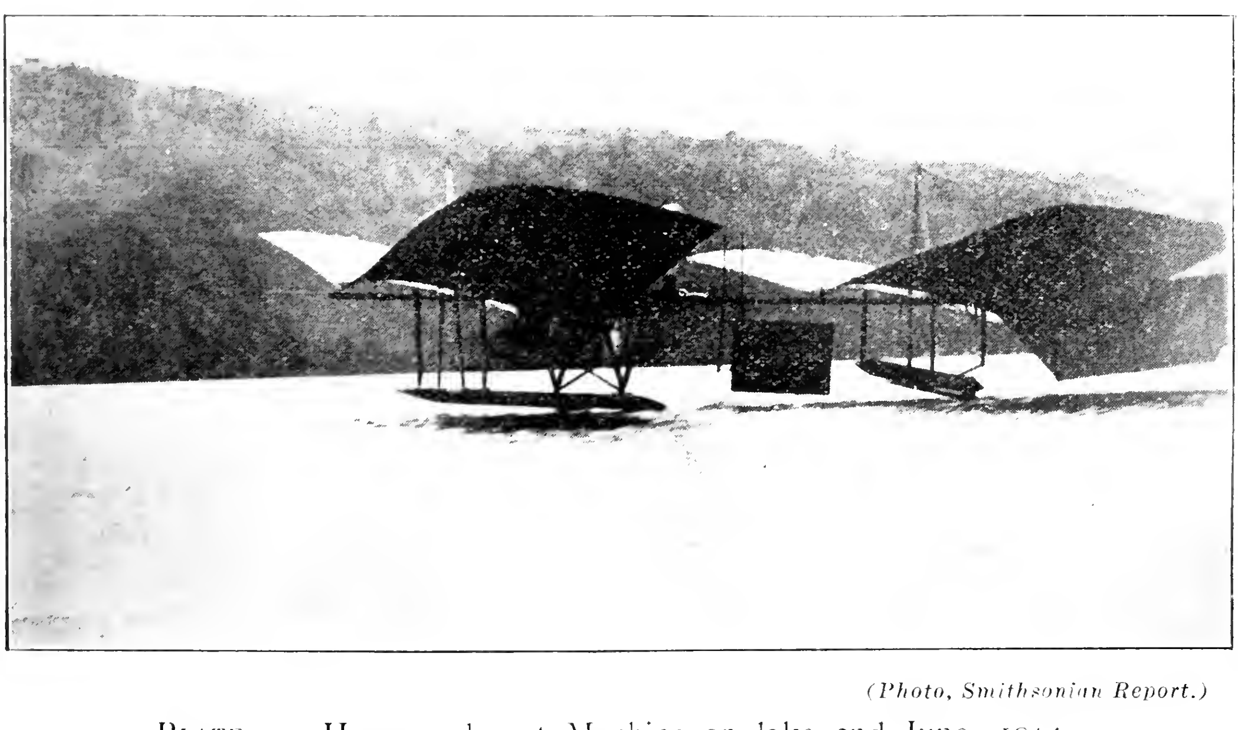
Manly. Zahm. Curtiss. (*Photo, Benner.*)

PLATE 7.—Hammondsport Machine. Note high A frames taking the place of Langley's short upper guy posts.



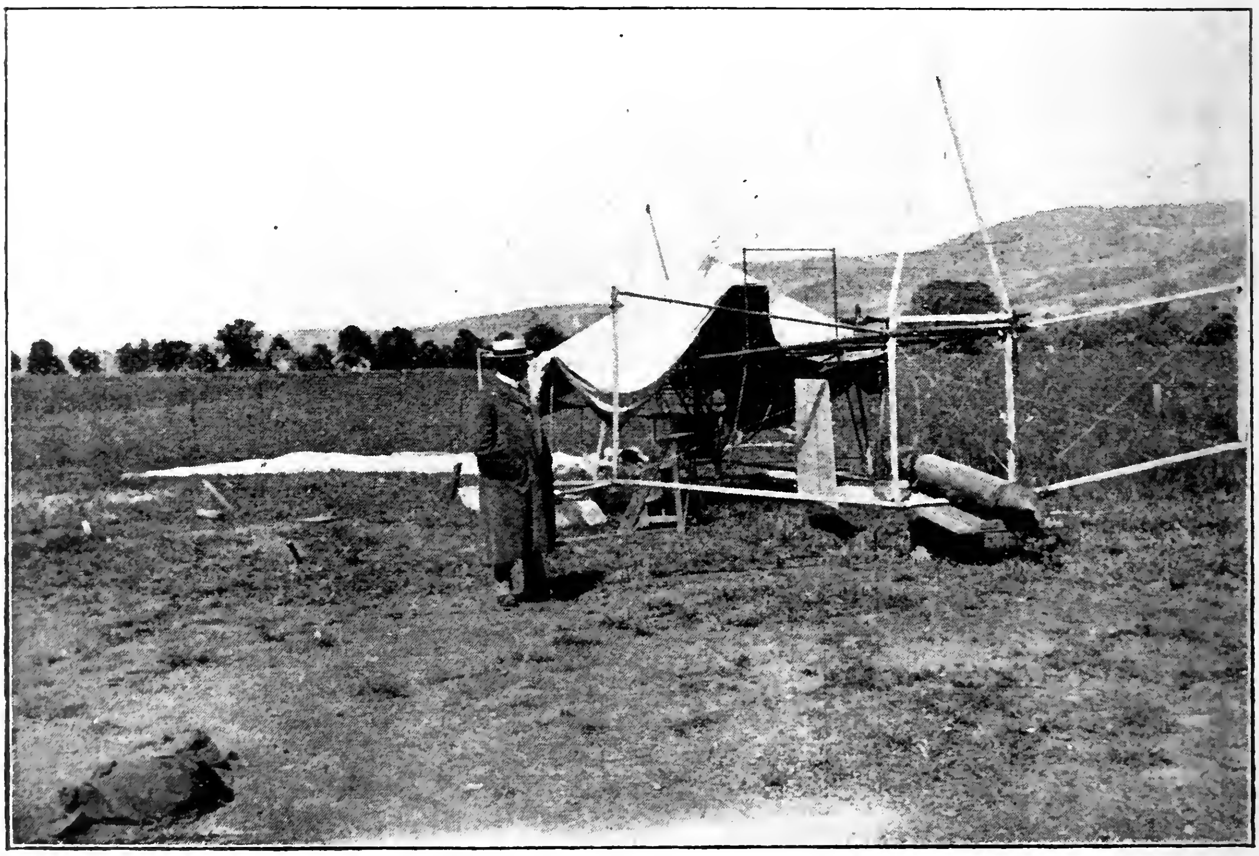
(Photo, Smithsonian Report.)

PLATE 8.—Hammondsport Machine. Note leading edge of wings terminating at front spars.



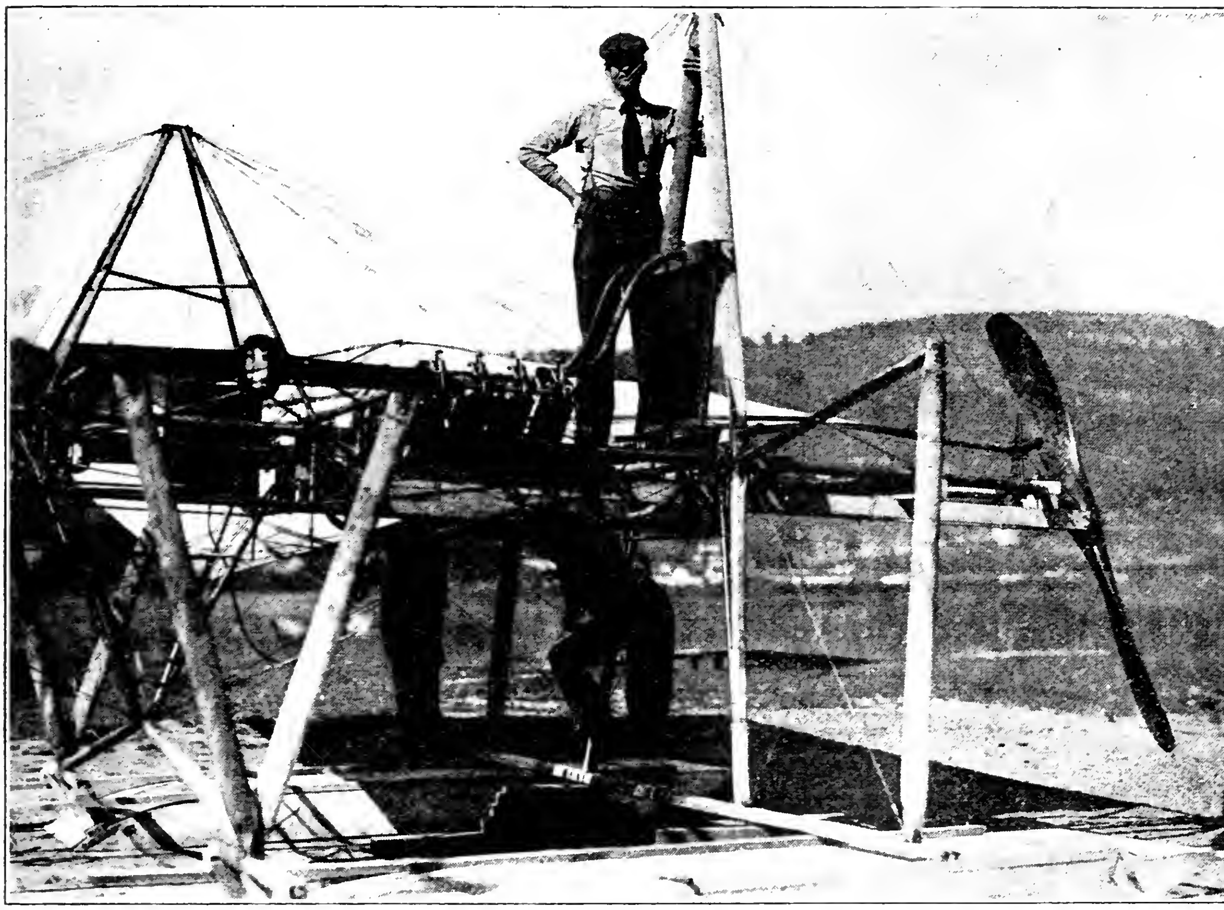
(Photo, Smithsonian Report.)

PLATE 9.—Hammondsport Machine on lake 2nd June, 1914.



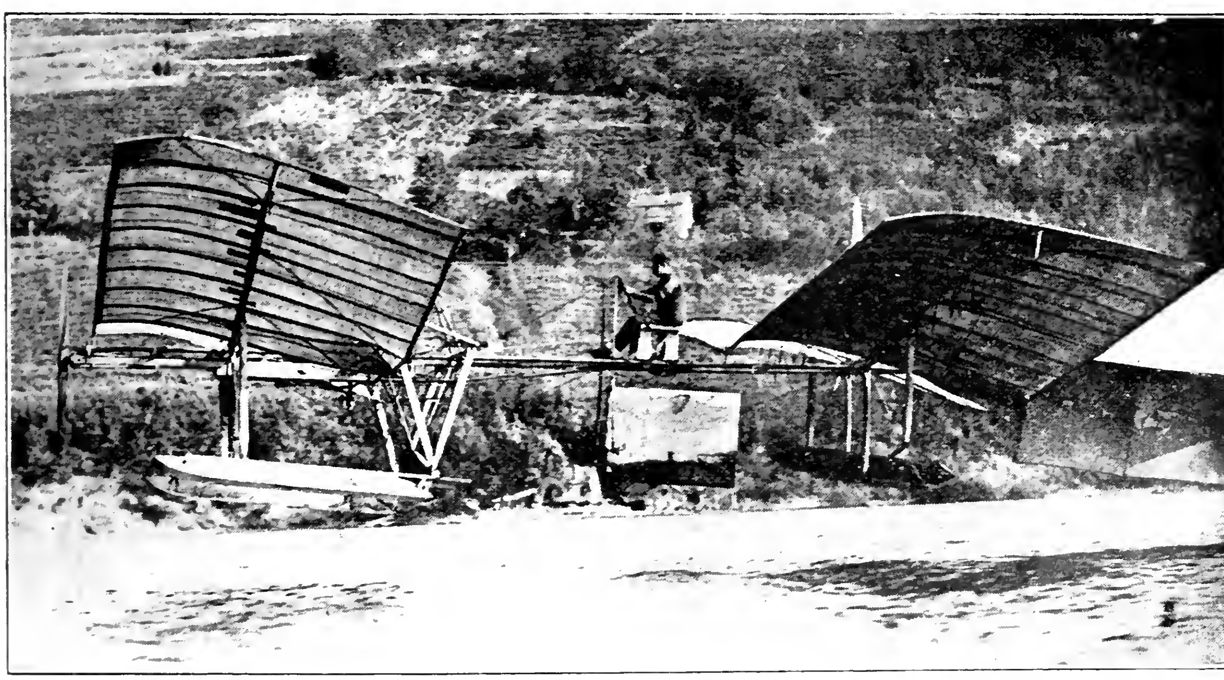
(Photo, Griffith Brewer.)

PLATE 10.—Hammondsport Machine, wings removed.



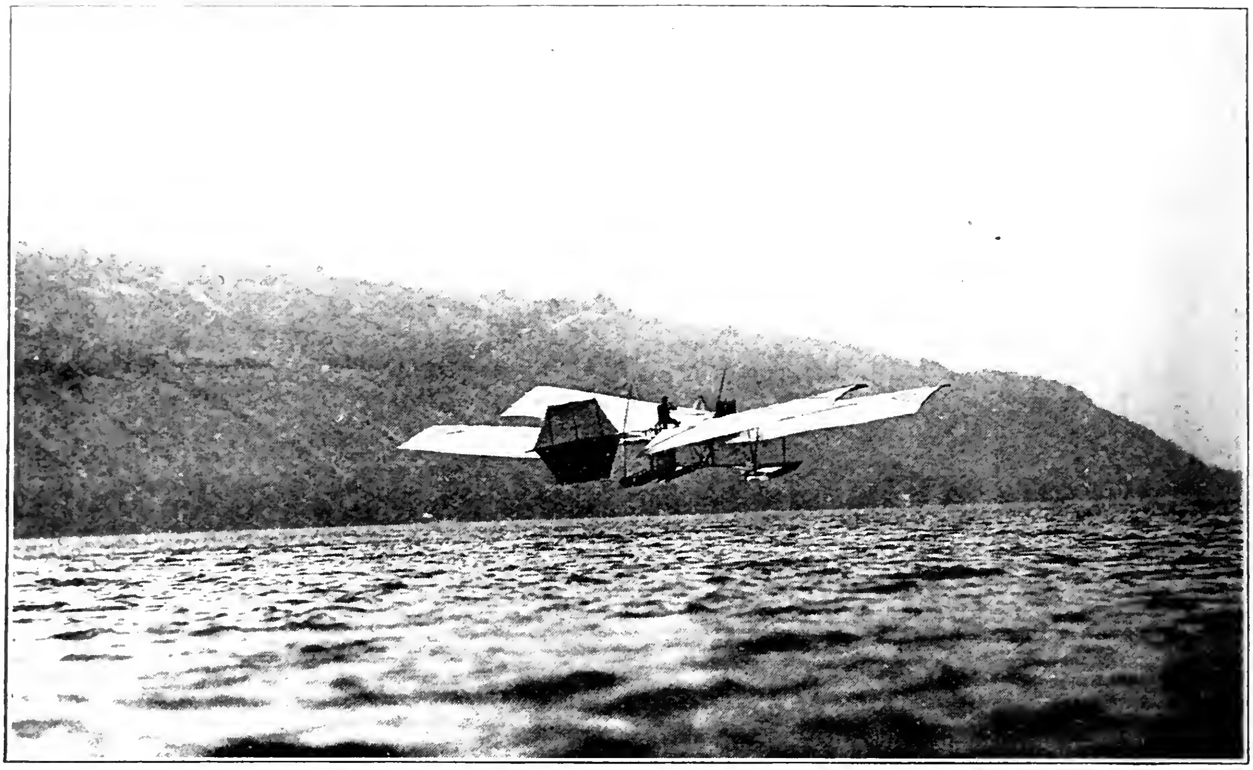
(Photo, Smithsonian Report.)

PLATE 11.—Hammondsport Machine with Curtiss motor, propeller, and modern radiator installed.



(Photo, Zahm Affidavit.)

PLATE 12.—Hammondsport Machine with Curtiss motor. Note position of pilot over frame, and front spars forming leading edges of wings.

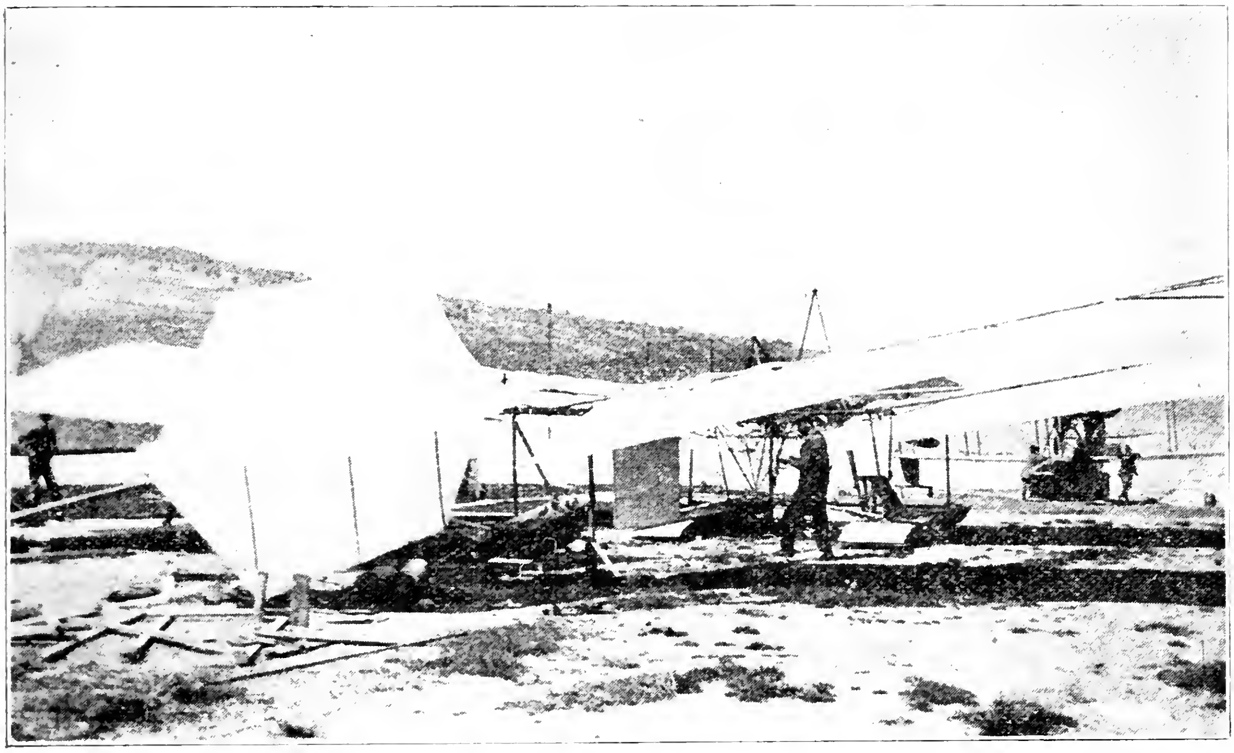


(Photo, Smithsonian Report.)

PLATE 13.—Hammondsport Machine over lake, 17th September, 1914.

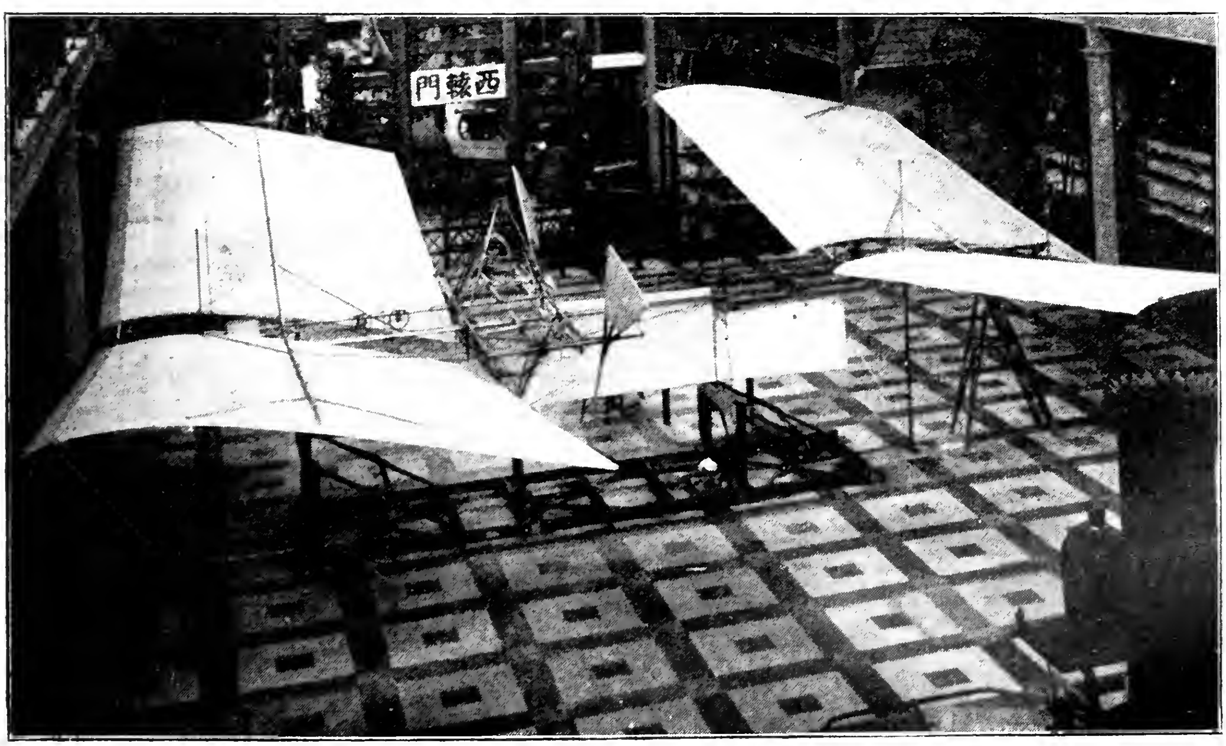
(Photo, Benner.)

PLATE 14.—Hammondsport Machine. Note further change in position of pilot.



(Photo, Lorin Wright.)

PLATE 15.—Hammondsport Machine, 4th June, 1915. Note reinstatement of short upper post over rear wings.



(Photo, purchased April, 1921, Smithsonian Institution.)

PLATE 16.—Reconstructed Langley Machine in Smithsonian Institution.

flat planes, as far as he was aware, and none of his laboratory work was with curved planes, whereas in the machine shown in the pictures by the lecturer, there curved planes were used of the order of 1 in 12, similar to that which Otto Lilienthal had in Germany. One wondered, therefore, whether there was not a gap in his experimental work which was not recorded.

In the present paper they had a good record of the historic research into what was and what was not done, and, as Colonel Ogilvie had said, the Wright brothers were fortunate in having so able and persistent an investigator as Mr. Griffith Brewer. He had unearthed a good deal of data which would otherwise have been completely lost. It seemed strange to think of procedure similar to what was adopted in America being carried out here. Could one imagine, for instance, two rival patentees discussing the steam engine and going to the South Kensington Museum, or somewhere else, and having out the original Watt engine, or some similar engine, and attempting to run it on the Great Western Railway to prove their point. To his unenlightened and English way of thinking it seemed extraordinary that a historical specimen of a machine should have been taken out from the Museum, where it very properly rested, and used for the purpose of determining whether or not the warping as laid down by the Wright patent was an essential feature or not, for the purpose of vindicating the Wrights' or Curtiss's claim. It seemed an extraordinary procedure to have adopted.

He thought everyone, from a historical point of view, owed a great debt of gratitude to Mr. Brewer for going so patiently and persistently through the details of all the experiments that were made.

The Chairman said, on behalf of the members, he moved a vote of thanks to the lecturer for his very interesting lecture. He had added to the sum of their aeronautical knowledge, and of human knowledge as well. As he had said, the lecture dealt with facts, and he (the Chairman) had no doubt the facts were as Mr. Brewer said. They would look forward with the greatest interest to any reply that might be received from the other side of the Atlantic.

From Dr. Walcott.

Smithsonian Institution,
Washington, U.S.A.,
October 10*th*, 1921.

Dear Sir,—With reference to the paper of Mr. Griffith Brewer on which you are so obliging as to request my comment, I regret very much that having been inaccessible in the field until October 9th I have not had time to take up the matter as thoroughly as I would have liked to do.

I take pleasure in saying at the start that the Smithsonian Institution fully recognises the well-deserved success of the Wright brothers in being the first to make actual flights in heavier-than-air power propelled machines. This recognition the Institution was among the earliest to make in a formal manner by an award of merit. This being so, I am not prepared to concede that the Wrights were the first to construct such a machine capable of such flight.

Mr. Brewer appears to claim :—

1. The Hammondsport experiments were made for Curtiss' ends at Curtiss' expense.
2. The changes made in guying the wings were indispensable to prevent their collapse.
3. The changes made in the engine were indispensable to make it run.
4. The changes made in the propellers were indispensable to give them sufficient thrust.

5. The changes made in the form of the wings were indispensable to flight.
6. The changes made in the rudder were indispensable to flight.
7. The Hammondsport tests of the original machine did not result in flight but merely in hops.

Mr. Brewer is misinformed in regard to some points, and I think imparts a false impression regarding others. I take up the points in the order just given.

I. I quote from my letter to Mr. Curtiss of March 31st, 1914:—

" In connection with the re-opening and development of work under the Langley Aerodynamical Laboratory, it seems desirable to make a thorough test of the principles involved in the construction of the Langley heavier-than-air man-carrying flying machine, especially the question as to the tandem arrangement of the planes, and general stability, especially longitudinal stability.

. . . . . .

" After my recent conference with you, I am writing to say that there will be an allotment of $2,000 made from the funds of the Langley Aerodynamical Laboratory for the purpose of conclusively testing the Langley machine and the principles involved in its construction. If you care to undertake such experimentation, will you answer at your earliest convenience? All materials connected with the original machine will be placed at your service for the purpose."

The Smithsonian Institution has still on file Mr. Curtiss' receipt for the payment made him in accordance with the above proposal.

II. Photographs show that in the original tests of the Langley machine, October 7th, 1903, one pair of wings stood up wholly without appearance of collapse after the machine took the air at full speed. Moreover, in the test of October 7th, 1903, the photographs show that the other pair was only slightly changed, and this change occurred for a very well attested reason, quite other than from their lack of efficient guying.

Mr. Brewer, in ignoring what follows on the same page, quite unfairly as it seems to me, quotes Mr. Manly's first statement to the newspaper reporters who beset him even before he was out of the water and who had to be pacified. Mr. Brewer should recognise that the succeeding well-considered statement by Manly and Langley after investigation of the causes of the failure of the test is the only one deserving of any weight:—

" After recovering the machine the foreman of the workmen (Mr. Reed) (who together with Mr. McDonald were the only ones on top of the boat when the launching actually took place), busied himself to discover what had caused the jerk to the machine at the moment it was released, which had been immediately followed by the great depression of the front end. After some little time he discovered that the upright guide at the extreme front of the launching car (which, as heretofore stated, was slotted to receive a metal lug projecting from the end of the guy-post, and thus prevent the front end of the framework from being twisted by a side wind striking the machine while it was still on the launching car) had been distorted, and the metal cap on it being stretched out of shape in a way which indicated that the pin of the front guy-post had hung in the cap, and that the guy-post was not therefore free from this part of the car when the end of the launching track dropped. The shock which the writer felt at the moment of launching and which had also been seen by others to occur was thus conclusively shown to have been due to the falling track, dragging the front end of the machine down with it. As the machine was travelling forward and the car had been almost instantly brought to a standstill by its buffer pistons co-acting with the buffer cylinders at the foot of the track, this front guy-post had been pulled backwards, and thus not only pulled the main guy-wires of the wings backwards and thereby

depressed the front edge of the front wings so that they had no angle of inclination, but had also bent the front end of the metal framework downward—effects which were discovered from the later examinations of the frame and the guy-post itself. From the instantaneous photographs which were obtained, indisputable evidence was obtained that this was what actually occurred. . . .

"After completing the recovery of the machine and the examination as to the extent of the injuries it had sustained, and finding unquestionable evidence that the accident had been caused by the front guy-post hanging in its guide block on the launching car, the workmen were set to work straightening out and arranging the various parts, fittings and accessories, and cleaning up the engine which fortunately had sustained no injury whatever. After a consultation in Washington with Mr. Langley, who had been unable to be present at the experiment, both concerning what had already occurred and also what should be done regarding the future of the work, and in view of the fact that the statement which the writer had given to the Press representatives, immediately after the accident, had been made before there had been time to make an examination of the machine itself, it was decided that it would be best to give to the Press a short statement to correct the earlier one, and Mr. Langley accordingly made public the following note:—

"'Mr. Langley states that he was not an eye-witness of the experiment at Widewater yesterday, having been detained in Washington by business, but that on the report of Mr. Manly, immediately in charge, he is able to say that the latter's first impression that there had been defective balancing was corrected by a minuter examination, when the clutch, which held the aerodrome on the launching ways and which should have released it at the instant of the fall, was found to be injured.

"'The machinery was working perfectly and giving every reason to anticipate a successful flight, when this accident (due wholly to the launching mechanism) drew the aerodrome abruptly downward at the moment of release and cast it into the water near the houseboat. The statement that the machine failed for lack of power to fly was wholly a mistaken one.'"

In view of these facts, I believe the photographic evidence of Langley's own tests of the great machine show that Mr. Brewer is wrong in maintaining that the Langley wings lacked efficient guying to prevent their collapse.

But one who knew Langley's work and the enormous mass of still unpublished tests of the wings, on the whirling table, with sand loading, and otherwise, and the experiments on lift, centre of pressure, and resistance for curved surfaces which occupied Mr. Huffaker many months, knows that Langley and Manly had sound experiments behind all they did and had not neglected to learn either the proper place or the sufficient strength for the guying.

III. The facts about the engine are quite opposite to Mr. Brewer's suggestion. In 1903 the engine ran far better than in 1914. There are many witnesses here who know that it ran with all five cylinders speaking for hours and hours at a time in 1903, delivering the full brake horsepower claimed by Manly. The Curtiss mechanics were unfamiliar with it, Mr. Manly was not present to instruct them until they had materially injured it by their unfamiliarity, and it never worked at Hammondsport anywhere nearly as well as in 1903.

IV. The propellers were cut down at Hammondsport, not because they could not hold up, but because the engine worked so poorly there that it did not run to speed with them. The thrust of the propellers at Hammondsport never exceeded 325 pounds, while in 1903 it was measured over and over again at 450 to 475 pounds with the original propellers.

V. The wings made at Hammondsport were far inferior in workmanship to Mr. Reed's wings. That they lacked the additional supporting surface of the overhang was to save time and expense, not for better design.

VI. Langley's whole energy was thrown to the single aim of making a single flight and a safe landing. He knew well that if this was accomplished the means to continue would be available. Owing to the wreck of October 7th, 1903, his means were exhausted before he got a flight. The rudder used in the 1903 tests was, as previous flights with the quarter size models had shown, adequate to guide a flight even without a pilot.

VII. I was present at Hammondsport on May 31st, 1914, and saw the machine with the original engine* giving only two-thirds the original thrust and with wings approximately of the original design, but far rougher executed, get under way from rest and fly gracefully, carrying, besides a man, over 300 pounds of floats in excess of what the machine was designed to carry. I am still confident that what it did under these relatively adverse circumstances is far inferior to what it was capable of doing in its original condition.

Very truly yours,
CHARLES D. WALCOTT,
Secretary.

Colonel W. Lockwood Marsh,
Secretary, Royal Aëronautical Society,
London, England.

* Mr. Brewer's Figs. 1 and 2 are wholly misleading. The earlier flights of 1914 were made with the original engine, the original propellers, and original cockpit. The later introduction of the Curtiss engine, traction propellers, etc., was for the purpose of gaining the further aerodynamical knowledge mentioned in my above cited letter of March 31, 1914.

From Dr. A. F. Zahm.

REVIEW OF EXPERIMENTS WITH THE REHABILITATED LANGLEY AEROPLANE IN 1914.

Origin and Motive of the Experiments.

The experiments with the rehabilitated Langley aeroplane, made by Mr. G. H. Curtiss, at Hammondsport, N.Y., in 1914, were initiated by the Smithsonian Institution for purely scientific purposes, were conducted at its expense, and were reported by its delegated observer, the Recorder of the Langley Aeronautical Laboratory, who then had no connection, either actual or prospective, with the Curtiss Aeroplane Co. These tests were no more initiated for the purpose of patent litigation than were Langley's original experiments, though both were later cited for that purpose.

The statement that none of the costs, apart from the carriage of the machine to Hammondsport, have ever been paid by the Smithsonian, is the irresponsible gossip of a partisan who could easily have ascertained the truth. To impugn the motives of the Smithsonian men associated with the work of retesting the Langley aeroplane in 1914 is a discourtesy and injustice that well might be discountenanced by an impartial society. Aside from the innuendoes and direct imputations, is it quite decorous to regale an honourable body of men with isolated bits of testimony selected from a compromised patent unit by a special pleader who paid a friendly visit to the complainant, but failed to interview the accused? Surely the members of a royal society cannot relish the false report of a partisan member upon the financial conduct of an honoured institution of a friendly nation.

Main Objects of the Tests.

As stated in the Smithsonian Annual Report for 1914, "The main objects of these renewed trials were, first to show whether the original Langley machine was

capable of sustained free flight with a pilot, and secondly, to determine more fully the advantages of the tandem type of aeroplane. . . . To achieve the two main objects above mentioned, the aeroplane would first be flown as nearly as possible in its original condition, then with such modifications as might seem desirable for technical or other reasons."

As the structural strength of the original machine had not been seriously questioned, no effort was now made to prove its adequacy. The prime effort was to prove (1) that the original machine could be propelled with its own power, (2) that it could be controlled in flight with the devices provided by Secretary Langley.

Claims of Other Aeroplane Inventors.

In the trials and reports of 1914 no attempts were made to belittle the work of other inventors. It was not claimed that Langley invented *the* aeroplane, or that he had brought in the era of practical flying. On the contrary, the printed report states that "the aeroplane as it stands to-day (1914) is the creation not of any one man, but rather of three generations of men. It was the invention of the nineteenth century; it will be the fruition, if not the perfection, of the twentieth century. During the long decades succeeding the time of Sir George Cayley, builder of aerial gliders and sagacious exponent of the laws of flight, continuous progress has been made in every department of theoretical and practical aviation—progress in accumulating the data of aeromechanics, in discovering the principles of this science, in improving the instruments of aerotechnic research, in devising the organs and perfecting the structural details of the present day dynamic flying machine."

The writer of that report had, in his book on aerial navigation, credited the English people with the invention of the chief essential elements of the aeroplane. Before the middle of the nineteenth century the English, notably Cayley and Henson, had provided these five essentials of a practical land aeroplane:—(1) A main sustaining plane suitably trussed and surfaced; (2) a vertical rudder; (3) a horizontal rudder or elevator; (4) an engine and propeller system; (5) a wheeled undercarriage.

With these five essential elements, as proved by many pilots, and notably by the French prior to the autumn of 1909, an aeroplane can make flights of more than an hour in fair or moderately rough weather.

The sixth essential element is the lateral rudder. This was invented and described by many persons prior to 1900. It received its first adequate experimental proof in the famous Kitty Hawk glider experiments, made at the beginning of the twentieth century.

Furthermore, the combination of said three rudders, in other words the three-torque system of control for an aeroplane, was invented and described by several persons prior to the year 1900. Goupil not only described the system in his book, but also embodied it in a proposed aeroplane which is now known to be operable under sufficient thrust.

What was Claimed for Langley.

The same report summarises the aerotechnic work of Dr. Langley as follows:—

"1. His aerodynamic experiments, some published and some as yet unpublished, were complete enough to form a basis for practical pioneer aviation.

"2. He built and launched, in 1896, the first steam model aeroplane capable of prolonged free flight, and possessing good inherent stability.

"3. He built the first internal combustion motor suitable for a practical man-carrying aeroplane.

"4. He developed and successfully launched the first gasoline model aeroplane capable of sustained free flight.

"5. He developed and built the first man-carrying aeroplane capable of sustained free flight."

Items 1, 2, 3, 4, were merely stated, because they were incidental to the report and did not seem to require proof.

What the Tests of 1914 Proved.

Claim 5 was proved by the Hammondsport trials of 1914, except for the item of structural strength. Mr. Manly's estimates and sand load tests indicated that the original machine was strong enough. If there be still sufficient doubt among competent engineers, the wing strength can easily be subjected to static analysis and a load test. But the bare statement, without figures, that the original wings were too weak should not be accepted by fair-minded men.

How then did the 1914 tests prove that the Langley machine of 1903 had in the air sufficient thrust and control for sustained flight? The principle of the proof is this, from the short flights of an overloaded and less efficient plane one may infer the feasibility of a longer flight with a lighter and more efficient plane of the same type.

The rehabilitated Langley monoplane which made short flights on May 28th and June 2nd, 1914, was under the following handicaps as compared with the original: (1) It weighed 40 per cent. more; (2) its wings had about 3 per cent. less area; (3) its resistance was much greater; (4) its propellers in all the tests gave less than 90 per cent. of the thrust developed in the 1903 tests.

Mr. Manly, who personally overhauled the engine, complained that it was below its normal power, and laid this to lack of adjustment and to the inadequate carburettor. Mr. Curtiss had the propellers reduced at the leading corners to allow faster rotation, but secured thereby no material increase of thrust. True, the over-all aspect ratio had been increased slightly; but what was the resulting gain in efficiency—3 or 4 per cent.? Certainly this was a trivial increase compared with the large handicaps.

From the fact that this abnormally small propeller thrust sustained a short flight of a greatly overloaded machine, with greatly increased frame resistance, it was inferred that the greater thrust on the less resistant plane of 1903 was sufficient to propel it in a longer free flight.

If an eagle with some wing feathers gone makes a short flight with a child in his talons, a scientist infers the possibility of a longer flight with unimpaired feathers and without the child. This inference might not be indorsed by a patent attorney or a partisan having some business interest to subserve.

To control the longitudinal poise of the Langley aeroplane, once in the air, only movement of the elevator was necessary. The large steering rudder was useful in maintaining a definite course and in parrying wind gusts that tended to rock the machine. All this had been demonstrated with French machines not having ailerons.

On the water it was obviously impracticable to cross the wind with the big tail fixed because it acted as a weather vane. It therefore was made to swivel about the vertical axis provided for that purpose in the 1903 machine. At the same time the vertical rudder under the main frame was locked and held as a fixed fin or keel in all the 1914 tests after the first one. So adjusted the control surfaces were not materially different in arrangement and function from those of the original Langley scheme, if one excepts the possible use of the underneath rudder as an aileron of short leverage. The Langley keel surface aft of the pilot's boat could obviously be used or not with immaterial difference.

The whole balancing and guiding of the 1914 machine, after May 28th, was effected with the double tail provided by Mr. Langley, turning about the horizontal and vertical axes provided by him. The mechanism for turning it, whether stick or wheel, is known to be immaterial. The essential thing is that these two movements were a part of the design for both the 1903 and the 1914 craft, and that they controlled the latter successfully. One may therefore conclude that the original machine could be controlled in flight with the double rudder provided by Mr. Langley.

It is obvious also to present-day engineers that the little rudder of the original machine, though not tested in 1914, was competent to steer the craft in the air, the big rudder being used only to control the longitudinal poise. The split-vane rudder of 1903 was more powerful than its substitute in 1914, for each of its surfaces measured 11.5 square feet as against 12 square feet in the single surface substitute.

The flights made after installation of the Curtiss engine and tractor screw allowed a fuller testing of the control surfaces. In all these flights when the line of gravity of the machine passed through the central pyramid, as in the original machine, the statical balance and the aerodynamic control were satisfactory. The separation of the pilot and propulsive plant in the later tests did not affect the statical balance, and therefore need not be urged as a serious objection in a test of the means for maintaining the equilibrium.

In all the tests the same wings were used, and were made partly of the original Langley hollow wood ribs, partly of new and solid wood ribs of the same size and shape. The hollow ones were strong enough, but too few; the new ones were made solid for economy. These wings were of the exact size and shape of those made by Mr. Langley without the sharply arched leading edge, and were not materially better than his hooked-nosed ones.

The upper king-post, which in 1903 supported either pair of wings, could sustain an end thrust of more than a thousand pounds. The down pull on it due to the wing weight alone was less than a hundred pounds. Still persons ignorant of theoretical mechanics assert that it was too feeble. Perhaps that is why the practical mechanics substituted such monstrous wooden struts; perhaps, too, they thought of the pounding on the waves. The Langley king-post was a tough steel tube 109 cm. long; 2.2 cm. in outside diameter; 0.100 cm. in wall thickness. Euler's formula shows that it should support 1,400 pounds, and therefore have a large safety factor during a sustained free flight of the 1903 machine. Partisan wiseacres contend that it was inadequate. They use but empty words, not figures. One deponent, who stalls at elementary statics, solemnly swore the little strut was weak. And blind Maeonides with golden chain now leads blind Thamyris, who sings aloud that sacred history to soothe the soul of ages still to come.

Definition of Sustained Flight.

In a quiet atmosphere an airplane executes sustained flight so long as its energy remains undiminished. For example, while its speed and altitude remain constant, or increase, its flight is sustained; that is to say, is perpetuated independently of its initial momentum. Thus, when the Langley airplane, on May 28th, was flying at steady speed and height, driven by the original engine, its flight was sustained till Mr. Curtiss cut off the power. Later, when the Langley airplane, driven by a Curtiss engine, flew half a mile at practically undiminished speed and altitude, its flight was sustained. The first flights have been called "short hops," the later "long hops." American pilots speak of crossing the continent in two or three hops. "What are words but birds that fly through the air and hurt not a stone?"

Summary of Results.

(1) The short flights of the overloaded Langley aeroplane in May and June, 1914, proved the propulsive system of the 1903 machine powerful enough for sustained flight.

(2) The half-mile flights made later in 1914, as well as the earlier ones, proved that the control surfaces of the 1903 aeroplane were sufficient to balance and steer the machine in the air.

(3) All the flights indicated that the hollow wing ribs were strong enough for the 1903 machine, but proved nothing for or against the adequacy of the general wing trussing. A special wing test could easily decide this question, if further evidence beyond that supplied by the original Smithsonian records be still required by a representative body of competent engineers.

Laundry List Objections.

It seems superfluous to notice seriatim all the trivial differences a hardware clerk can find between the Langley aeroplane of 1903 and that of 1914. Multitudinous, minute, inconsequential, they read like a laundry list. And if a thousand objections were answered, a thousand more would follow. In the list of changes why should the colour escape attention? A canary yellow wing differs from a faded buff.

Conclusion.

The foregoing paragraphs, written on too short notice, treat some of the major questions at issue. If the summarised inferences cannot be admitted, neither have they been disproved. A strut is not weakened by denying its strength. The objections so far offered have little cogency, for they are mainly declaratory and statistical. They are the objections of a book-keeper rather than of an engineer. But they doubtless have as much potency as the arguments of those mighty mathematicians who used to prove the impossibility of sustained free flight in any possible aeroplane of man's contrivance. And they have the merit of separating Langley's upright life from association with anything which is not strictly true or honourable.

Epilogue.

The foregoing paper, prepared by invitation of the Council of the Royal Aëronautical Society, was forwarded to the Secretary with the following recommendation :—

"Permit me very respectfully to recommend to the Council that it rigorously delete from the papers presented in this case, pro and con, all harsh personalities, all innuendoes and imputations of bad faith, as unbecoming to the dignity of scientific discussion, and distasteful to the urbane and cultured audience of a royal society."

Cosmos Club, Washington, D.C.,
October 10th, 1921.

From Mr. C. M. Manly.

I would have been amazed at the contents of this paper by Mr. Griffith Brewer had I not, upon reading it, immediately recalled the great similarity between a large portion of the statements made in it and the very bald statements made in the affidavit of Mr. Orville Wright in the suit of the Wright Company *v.* the Curtiss Aeroplane Company in 1915, in which Mr. Wright claimed for himself

and his brother the credit for everything that had been achieved in aviation from the beginning of time, and had dismissed everything that went before as "mere speculation and theory excepting," as he described it, "the desultory experiments of men like Lilienthal and Chanute with powerless gliding machines, and like Maxim, Ader and Prof. Langley, with miniature models and experimental full-sized machines which never flew, nor were capable of flight." In fact, it appears, upon a review of this affidavit of Mr. Orville Wright, that the present paper by Mr. Brewer is merely a condensed statement of the assertions, arguments, speculations and errors of this affidavit by Mr. Wright.

Before discussing Mr. Brewer's paper in detail, I wish to say that there is no one more willing and anxious to give due credit to Mr. Orville Wright and his late lamented brother, Mr. Wilbur Wright, for the brilliancy of their achievement in building the first machine that actually transported a human being through the air in controlled flight, as well as for being the first to actually fly in such a machine, and also for their great ability and pluck in achieving these results entirely through their own resources. I do deny, however, that the machine which they built and with which they accomplished the first flight was the first full-size machine capable of controlled flight, and I do assert that the Langley machine, which was built prior to theirs, was capable of successfully transporting a human being through the air and being controlled in such flight, and that it was prevented in 1903 from actually demonstrating its ability to achieve this result entirely through unfortunate accidents in connection with the two launchings which were made of it, and not through any inherent weakness, inefficiency, lack of power, or lack of any essential element necessary to the securing of such a result.

It must be remembered, in connection with the large Langley machine, that the general plans for it had been settled by Dr. Langley prior to my becoming associated with him in June, 1898. Also that these plans called for this large machine to be as near a duplicate as possible, on an enlarged scale, of the two steam-driven models which had so successfully flown in 1896 and which were approximately one-quarter the linear dimensions of this large machine. While Dr. Langley had, from the beginning of the undertaking, felt that it was necessary to replace the steam power plants of the successful models of 1896 with an internal combustion engine, and recognised the securing of such a power plant as being probably the most formidable obstacle to be overcome, still he felt that in an art which was so new and in which there was practically no other proved experience than these successful models to guide him, it was fundamentally important to rigidly adhere to the general design of the successful models, and not to change the design in any particular, except where absolutely necessary, at the same time that the scale of the machine was being changed. While, therefore, many proposals were made and discussed with reference to many of the features of the machine, which it was recognised would need to be changed before it would be thoroughly practicable for war or commercial purposes, still he resolutely brushed aside all such proposals that were not felt by him to be necessary in securing the one first object, that of enabling the machine to prove the practicability of transporting a human being through the air in controlled flight, by actually doing so under the guidance of such an operator. It is, therefore, to be understood that the Langley Memoir, to which Mr. Brewer refers, was prepared by me in such time as I could spare from an otherwise busy life, after ceasing my connection with the Smithsonian Institution, and that it was not intended as a treatise on the subject of aviation, but merely as an historical record containing such manuscript as Dr. Langley had himself, prior to his death, prepared, relating to the steam-propelled models, supplemented by a description of what seemed to me to be the more important constructions and tests carried out during the several years that I was associated with him. In fact, the draft of the entire manuscript which I prepared for this publication was completed prior to the fall of 1907, but

owing to the extreme pressure of other matters which could not be postponed, I was unable to complete the review and proof reading and release the manuscript for publication until I again took it up, in 1911, after a lapse of four years. The period of time, therefore, between the actual carrying on of the work and the writing of the manuscript record of it was not so great as would be supposed from the fact that the volume was not published until 1912.

It had been my hope and ambition, on closing up the work of Dr. Langley in 1904, as stated in the Langley Memoir referred to, to personally provide the necessary funds and to personally make a further test of the machine to demonstrate that it would fly successfully, exactly as it was attempted to fly it in 1903, and thus achieve what Mr. Brewer very aptly describes as "one of the most dramatic events in the history of aviation." However, fortune did not smile on me to the extent to enable me to personally meet the expense which such a demonstration would involve, and, consequently, I was very much pleased in 1914 when I learned that Dr. Walcott had arranged for the Langley machine to be tested by Mr. Curtiss at Hammondsport. Unfortunately I was not present at any of the tests of the Langley machine at Hammondsport, and therefore did not have the satisfaction of seeing it fly equipped with its original motor and carrying a load of approximately forty per cent. more than we had burdened it with in 1903. However, I did see the machine itself when I visited Hammondsport on June 30th, 1914, and was most bitterly disappointed to find not only that in rebuilding the wings such portions of the structure as had had to be supplied to supplement the spare parts which we had remaining after the second trial in December, 1903, were so crude and the wings so roughly assembled that it seemed hardly possible that the machine could be expected to fly with such crude and poorly assembled wings, but that the engine and transmission and propeller shafts had been so greatly abused by attempting to run the engine without having it in proper adjustment, that I was more than ever surprised that the machine would fly under such conditions carrying even its original weight, much less its greatly increased weight, as well as greatly increased head resistance, which had been added to it in mounting it on pontoons.

From what I did learn when I was at Hammondsport on June 30th, 1914, from personal interviews with various eye witnesses of the tests which had previously been made of the machine, I was convinced, however, that the machine had been successfully flown for short intervals on several occasions previously, and that this had been accomplished in spite of the fact that at no time had the original Manly motor, with which it was equipped, been operating at anything like the power that it was capable of giving, as shown by the previous tests in 1902 and 1903, this lack in power being due solely to the improper adjustment of the engine and its being equipped with a carburettor which was either not suited to it or not adjusted to give the best performance. When I left Hammondsport on this visit of one day only, I was assured that the defects in the adjustment of the engine would be remedied and the ball bearings on the transmission and propeller shafts, which had been damaged, would be repaired before further tests were made with it. I later understood, however, that the engine was removed and a Curtiss engine substituted in order to avoid both the danger of damage to the original engine and the delays which it was feared would be encountered in keeping the ball bearings of the transmission shafts in proper repair, and that as the original engine had already demonstrated its ability to successfully propel the machine, such further tests as were desired in connection with the study of the machine aerodynamically could be accomplished more expeditiously with an engine driving a single propeller without the use of gearing, etc., required by the original engine and its dual propeller arrangement.

Referring, now, more specifically to the criticisms which Mr. Brewer has made under the heading, "Original Langley Flying Machine, 1903," Mr. Brewer's statement in the third paragraph under this heading that the evidence

which he was presenting "is only a part of the evidence in my possession" is very apt indeed, for it is quite apparent that in attempting to prove his point he has deliberately suppressed part of the evidence which he had in his possession. For example, he has quoted in full from the Langley Memoir the statement which I made to the Associated Press, immediately after my emergence from the water and return to the houseboat, following the launching of the machine on October 7th, 1903, but has not quoted what is stated in the Memoir—that "although his (my) first inclination was not to make any statement (regarding the test) until a complete examination could be made to determine both the cause of the lack of success and also the extent of the damage which had been sustained by the machine, yet owing to the very great pressure brought to bear by the Press representatives, who said that unless some statement was given out they would write their own conclusions as to the cause of the mishap, he (I) finally gave out the following statement," the statement which he quotes. Nor has Mr. Brewer seen fit to quote you the immediately succeeding paragraph which reads as follows:—

"After recovering the machine, the foreman of the workmen (Mr. Reed) (who together with Mr. McDonald were the only ones on top of the boat when the launching actually took place), busied himself to discover what had caused the jerk to the machine at the moment it was released, which had been immediately followed by the great depression of the front end. After some little time he discovered that the upright guide at the extreme front of the launching car (which, as heretofore stated, was slotted to receive a metal lug projecting from the end of the guy-post, and thus prevent the front end of the framework from being twisted by a side wind striking the machine while it was still on the launching car) had been distorted, the metal cap on it being stretched out of shape in a way which indicated that the pin of the front guy-post had hung in the cap, and that the guy-post was not therefore free from this part of the car when the end of the launching track dropped. The shock which the writer felt at the moment of launching and which had also been seen by others to occur was thus conclusively shown to have been due to the falling track, dragging the front end of the machine down with it. As the machine was travelling forward and the car had been almost instantly brought to a standstill by its buffer pistons co-acting with the buffer cylinders at the foot of the track, this front guy-post had been pulled backwards, and thus not only pulled the main guy-wires of the wings backwards and thereby depressed the front edge of the front wings so that they had no angle of inclination, but had also bent the front end of the metal framework downward—effects which were discovered from the later examination of the frame and the guy-post itself. From the instantaneous photographs which were obtained, indisputable evidence was obtained that this was what actually occurred. Referring to the photograph, Plate 95, which was taken by Mr. G. H. Powell, Secretary of the Board of Ordnance and Fortification, and which shows the machine just a few feet in front of the point where it was actually launched, it will at once be seen that the front end of the frame is bent downward and that the front guy-post instead of being parallel with the rear one has been deflected backward at the lower end through an angle of thirty degrees. Referring further to the photograph, Plate 96, which was taken at the same instant as the one just described, it will be seen that even this one, which is a view of the machine as it passed almost directly over Mr. Smillie's head, most clearly shows the extreme extent to which the front wings had been distorted, the rear edges of the wings near the frame having been twisted up until they struck the cross-frame, and the outer ends being free to twist had been forced up very much higher."

Neither does Mr. Brewer, in his immediately preceding quotation from Mr. Reed's affidavit, see fit to give you sufficient from the said affidavit to enable you to see that Mr. Reed's use of the expression, "it appeared at first," refers merely to an instantaneous impression which he immediately corrected by making an

immediate examination of the launching car to determine what had caused the machine to plunge downward at so sharp an angle, and that it was he who immediately discovered that the front guy-post had hung on the launching car, as evidenced by the distortion of the metal fitting of the car on which the guy-post had hung. Furthermore, Mr. Brewer is very careful to call your attention to the distortion of the front wings, as shown in these two photographs and as described in the Memoir in the paragraph which he omitted, but he does not call attention to the fact, which was called attention to in that paragraph, that the photograph taken by Mr. G. H. Powell, Secretary of the Board of Ordnance and Fortification, and which he has reproduced as Plate 3, shows very clearly that the lower guy-post of the front wings has been bent back by its having hung on the launching car, and that through such hanging it has twisted the bowsprit and front nose of the framework around through an angle of twenty degrees or more, thus permitting these front wings to twist as described in the said paragraph. Mr. Brewer's statement that " it also will be observed that the rear wings are likewise distorted, though to a less degree," is a mis-statement of fact, as there is no distortion of these rear wings, either in Plate 3 or in Plate 4. In fact, there is nothing more noticeable on Plate 4 than that the rear wings are not in the least distorted, although they must have been supporting their portion of the weight at the time, while the front wings are distorted, as would naturally be expected with the front guy-post bent backwards to the position shown in Plate 3.

Mr. Brewer's statement is misleading in connection with his reference to the metal cap, which held the front guy-post from rising during the launching, having had to sustain the entire lift of the wings during such launching, since the metal cap would only have to sustain such lifting force of the wings as was in excess of the weight of the machine at that end, and as the launching speed was made to be the same as the soaring speed, there would not be any lifting force of the wings in excess of the weight except such as might come from a wind, and it was not expected that the machine would be launched at first in anything but a generally quiescent atmosphere, and there was no appreciable wind blowing when the machine was launched on October 7th, 1903.

It is also noted that among the other evidence in Mr. Brewer's possession, which he has failed to lay before you, is the statement which Dr. Langley made to the Press on the next day to correct the earlier one which I had given to them before having had an opportunity to examine the machine, or even to think quietly about the matter. Dr. Langley's statement was as follows:—

" Mr. Langley states that he was not an eye-witness of the experiment at Widewater yesterday, having been detained in Washington by business, but that on the report of Mr. Manly, immediately in charge, he is able to say that the latter's first impression that there had been defective balancing was corrected by a minuter examination, when the clutch, which held the aerodrome on the launching ways and which should have released it at the instant of the fall, was found to be injured.

" The machinery was working perfectly and giving every reason to anticipate a successful flight, when this accident (due wholly to the launching mechanism) drew the aerodrome abruptly downward at the moment of release and cast it into the water near the houseboat. The statement that the machine failed for lack of power to fly was wholly a mistaken one.

" The engine, the frame, and all the more important parts were practically uninjured. The engine is actually in good working order. The damage done was confined to the slighter portions, like the canvas wings and propellers, and these can be readily replaced.

" The belief of those charged with the experiment in the ultimate successful working of the machine is in no way affected by this accident, which is one of the large chapter of accidents that beset the initial stages of experiments so novel as

the present ones. It is chiefly unfortunate in coming at the end of the season when outdoor work of this sort is impossible.

"Whether the experiments will be continued this year or not has not yet been determined."

Mr. Brewer's supposition that I did not feel, or remember, until some years later, the shock experienced in launching is quite in keeping with the many inaccuracies of statement which he has made in the paper, as could be very easily demonstrated, were it desirable to do so, by the testimony of a number of those who were present at the time and with whom I discussed the matter while we were investigating the cause of the machine having pitched downward at such a sharp angle when it was launched.

Referring to Mr. Brewer's comments on the second launching of the Langley machine on December 8th, 1903. Mr. Brewer has not seen fit to even mention that, although the conditions at the moment of launching had become so bad, due to the fact that the houseboat, which could not be controlled by the tug-boat which was lashed to it, was veering rapidly under the combined influence of a strong tide and a strong counter wind, and that this combined with the lateness of the hour and the river being full of floating ice, made it most hazardous to attempt to launch the machine, still, owing to the depletion of the available funds and the feeling that it was "then or never," as explained fully in the Langley Memoir, I decided to take a chance. It was, no doubt, a grave error in judgment, but under the stress which existed at the time it was perhaps human, if not pardonable. What really occurred in the second test I have set out to the best of my ability in the Langley Memoir. It may be briefly summarised into the statement that with the boat swinging first in one direction and then in the other, as it was under the counter influence of the wind and tide, the machine was caught, while running down the launching track, by a wind gust striking it from a direction that it was not any more prepared to meet, or designed to meet, than many later and unquestionably successful machines, which have been wrecked by wind gusts on a flying field, and that the large tail rudder at the rear dropped down at its rear end to the track as the machine was running along it, and that this pulled the entire machine down into the launching car at the moment of launching so that both rear wings were destroyed along with the rudder, and the right hand front wing, and probably the front guy-post, were similarly damaged, as the bowsprit is seen very clearly in Plate 5 to be bent down somewhat as it was in Plate 3. What probably gave way first was the upper guy-post of the large rear rudder and tail. This guy-post, which was at the extreme rear of the main frame, does not happen to show in any of Mr. Brewer's plates, but is shown very clearly in Plate 53 of the Langley Memoir. It is there indicated by the numeral 43, being provided at its upper end with a pulley over which ran the upper control wire by which this tail was operated up and down for longitudinal balancing and steering vertically. This guy-post was braced by a horizontal wire 44 running from the top of it to the upper guy-post of the rear wings. As the swivel mounting of this large rudder had been clamped to the short vertical tube at the rear of the machine to prevent the rudder from turning in a horizontal direction during this first test, leaving it free to be operated up and down only, it was expected that the only pull which this rudder would exert on this rudder guy-post would be straight backwards and downwards, and therefore it was not braced except in this direction by this single wire just described. It is quite probable, therefore, that with the houseboat swinging around as it did, the clamping of the swivel fitting of the rudder did not hold it against swinging around under the influence of the wind striking it from the side, and that this caused the rudder to pull on this guy-post in a direction diagonal to this horizontal bracing wire at the top of it, and that the guy-post gave way under this diagonal pull, thus permitting the rear end of the rudder to drop to the track, which would readily account for all of the resultant pulling of the machine down into the

launching car when it was released and the smashing up of the rudder and rear wings and the damaging of the front wings, as seen in the photograph, Plate 5. I do not assert, however, that we know definitely that this is the way in which the accident started. I have stated very frankly in the Memoir that we did not know definitely exactly how the accident started, or the sequence of events, except that the large tail rudder was seen by Mr. Reed to be dragging on the track at least ten feet or more before the machine was launched, and that the smashing up of this tail rudder by this dragging of it caused the whole machine to be pulled down into the launching car when it was released, resulting in the damage already described. Mr. Brewer, who was not present, maintains that he knows all about it, and that it was caused by weakness of the wing structure, but none of the score or more of those who actually witnessed the accident were able to give any description of just what occurred first earlier than their seeing the tail rudder dragging on the track, though all who were able to give any detailed description of what they saw concurred in stating that the tail rudder was dragging on the track before anything else appeared to go wrong.

Regardless, however, of whether or not the accident in launching the machine on December 8th, 1903, was due to a side wind striking it, the main point is that the machine, both in design and construction, was sufficiently strong to safely transport itself and its operator under the quiescent atmospheric conditions for which it was designed and under which the first tests were supposed to be made. The rear wings and the tail rudder with its operating cables and supporting guy-posts had shown no weakness in the first test on the 7th of October when the tail rudder was subjected to even heavier stresses than it would normally be called upon to withstand, due to my having pulled it up to the upper limit of its motion, or negative angle, in trying to right the machine when I found it plunging nose downward in this test.

There is no foundation for Mr. Brewer's statement that "there were several perfectly good reasons why the wings would collapse under any conditions of the launching." He cites as one of these reasons an alleged weakness of the cross ribs of the wings as shown in the sand loading tests, for which the deflection figures are given in the Memoir, and states that "when a sand load of only twenty per cent. above the flying stress was imposed, most of the ribs were bent from twelve to thirteen inches out of shape." He does not in any way distinguish the difference between flexibility and weakness. Dr. Langley's method of development was not to guess at anything, or depend on mathematical computation, where exact data could be procured by tests. It was for this reason that he devised, many years before I was associated with him, the scheme of loading the wings with sand to predetermine not only whether they were strong enough to stand the loads which it was known they would have to meet, but also to determine whether the change in contour was sufficient to interfere seriously with their effectiveness as supporting surfaces. Dr. Langley insisted most strongly at all times on the wing structure being kept as flexible as possible without such flexibility militating too greatly against their effectiveness. His opinion was that if the wings were too rigid in the early experiments, it would result in the machine being much less stable, and his great concern at all times was to minimise, as far as possible, the danger of a fatal accident occurring in the early trials before the operator had become sufficiently experienced to be able to manage the machine effectively. His greatest concern at all times was longitudinal stability, and he felt that this must be automatically maintained, certainly until the operator became quite experienced in controlling the machine. He insisted, therefore, that the wings for the large machine, especially at their trailing edges, should have practically the same degree of flexibility in proportion to their size as the wings of the successful models had. The cross-ribs, while, therefore, flexible to the extent shown by the deflection figures in the sand load tests, were not weak, but even stronger in proportion to the load they had to carry than those of the successful

models which had not only shown no weakness in flight, but had not even been broken in many of their landings on the water. The wings on the quarter-size model, which flew on August 8th, 1903, were proportioned in all their parts with reference to the corresponding parts of the large machine in exact accordance with the relative weights of the two machines, and there was certainly no weakness apparent in this quarter-size machine. A number of very clear photographs of it in flight are given in the Memoir.

In discussing the position of the guy-posts and the centre of pressure on the Langley machine, Mr. Brewer makes the statement, "Mr. Langley had made no measurements to locate the centre of pressure at small angles." He thus asserts as a fact what is untrue. For several years before I became associated with Dr. Langley he had been making a very thorough study, by actual tests, on the whirling table of the position of the centre of pressure of a score or more different shapes of curves supporting surfaces, a large number of these being indicated by the letter "T" in Plate 48 of the Memoir, where they are shown hanging on the wall in the background of the picture. Furthermore, in the Memoir, in describing the supporting surfaces, I have stated that the main rib (or wing beam) was placed at approximately the point where the centre of pressure of the wings was at their flight angle of ten degrees, and that this main rib was located at about forty per cent. from the leading edge of the wing. The reason the guy-posts were located as they were on the large machine was solely and only because they had been located at this point on the small machines, and that shop tests of both machines had shown that the system of guying was thoroughly strong and effective.

Mr. Brewer has made great point of the fact that the camber of the wings of the Langley machine in the Hammondsport test was not the same as that of the wings in the tests of 1903. I have clearly stated in the Memoir that the wings for the large machine were originally made with a one in eighteen camber, and that later when the rib construction was improved and the wings, which were finally used in 1903, were made in 1900, the front extension or leading edge was added, which changed the camber to one in twelve, to make these wings more nearly a duplicate of the wings of the steam-driven model No. 5 which had flown in May, 1896, instead of like those of No. 6 which had flown on November 28th, 1896, as they were originally planned to be. Both of these wing curves had given very good results on the whirling table tests, and Dr. Langley favoured the one in twelve camber and ordered it used in the final wings. It is quite certain that, aside from the greater cost of building the wings with this front extension, there would have been no particular difference in the results of the Hammondsport tests had they been so built. I am quite certain that any unprejudiced observer, who could have seen the Langley machine as it was rigged up at Hammondsport with the heavy floats attached to it and with the heavy, cumbersome system of rough struts and braces used in attaching it to the pontoons, would not have thought that it stood as good a chance of making a successful flight, using the crudely constructed wings with which it was equipped, as it would in exactly the condition obtaining in the tests in 1903, or as it now is in the National Museum in Washington.

Owing to the very brief time available between the receipt of the advance copy of Mr. Brewer's paper and the close of the last mail which will enable these comments on it to reach London by October 20th, it is impossible to attempt to go into Mr. Brewer's paper in more detail. I will only add, as I have always stated and do affirm, that the accident in the test of October 7th, 1903, was due entirely to the hook on the end of the lower front guy-post catching in the launching car, and that but for this accident a successful flight would, no doubt, have been achieved on October 7th, 1903. I have always and do still maintain that the accident to the machine on December 8th, 1903, was due to its being caught in a squally wind, which, under the influence of the counter force of the tide and wind,

caused the houseboat to swing around in such a way that the machine was subjected to stresses which it was not expected that it would be subjected to, nor necessary that it be subjected to, in order to give it a test in free flight, and that the machine, exactly as it existed in December, 1903, was thoroughly capable of making a successful flight and demonstrating that it was the first machine constructed in the history of the world capable of successfully transporting a human being through the air and being properly controlled in such flight. The tests at Hammondsport certainly demonstrated that the machine was capable of doing more than had ever been expected of it in the matter of carrying weight, and that the original engine with which it was equipped not only furnished sufficient power to enable it to carry its original weight, but also a greatly increased weight requiring considerably more than fifty per cent. more power than the original weight required, and that the claim is thoroughly well founded that it was the first machine built capable of safely transporting a human being through the air and being properly controlled in such flight.

From Mr. Glenn H. Curtiss.

Garden City,
New York.

THE TRIALS OF THE LANGLEY FLYING MACHINE AT HAMMONDSPORT, N.Y.

I have read the proof of Mr. Brewer's Paper on the Langley Flying Machine. In the first paragraph Mr. Brewer quotes Lord Northcliffe as saying that " in the United States there have been long and persistent attempts to belittle the work of Orville and Wilbur Wright." I think Lord Northcliffe has been misinformed. Personally, I have always thought the Wrights are entitled to and have received full credit for having invented and built the first airplane to make successful flights. The Langley Flying Machine of 1903 *did* however fly in 1914 at Hammondsport, N.Y., in its original condition with its original motor and propellers with no alterations except the addition of floats and their necessary supports, weighing altogether 350lbs. On several occasions this original machine rose from the water and flew for a short distance, and there is at least one photograph of the machine in the air.

Some time prior to June, 1914, I received a letter from Dr. Walcott, of the Smithsonian Institute, stating that an appropriation had been made by the Trustees of the Institute for the expenses of having the original Langley Flying Machine of 1903, which had been wrecked in launching at that time, given a trial flight and asking if I cared to undertake the commission. As we had every facility for doing the work and were very much interested in learning what the Langley machine would do, I replied that I would accept the commission. The machine was shipped to Hammondsport and assembled for the trial. We fitted three pontoons, two forward and one aft. The two forward pontoons were placed in such a position under the forward wing so that the angle of the guy wires leading from the wings would be unchanged. It was, of course, necessary to remove the long post to which the lift wires had been attached when the machine was launched from the catapault. I personally made the early trials and succeeded several times in rising from the water and flying for a short distance, carrying the additional head resistance and weight of the pontoons and fittings, which latter we found was about 350lbs. The dihedral wings gave excellent stability, and we were so pleased with the fact that we were able to fly the machine with this great amount of extra weight that we asked permission to instal a more powerful motor with a direct drive propeller and make more extended flights. This installation was made and flights were then made with the machine by two of my assistants,

Mr. Doherty and Mr. Johnson. Mr. Doherty made some flights in quite badly disturbed air.

The facts are that the Langley machine was not only flown with the same identical motor, propellers, wing surfaces and general construction, but carried the additional weight of 350lbs., and still further that with increased motor power it flew and carried an added weight of about 800lbs., including the extra weight of the motor.

Mr. Brewer did not make his presence known at Hammondsport, and I had no knowledge that he was there. I was afterwards told he had been sent there by the Wrights, to gather evidence for their suit to show that the Langley machine was not a practical flying machine.

GLENN H. CURTISS.

Mr. Griffith Brewer, replying to the discussion, thanked Colonel Ogilvie and Mr. Handley Page for the very kind things they had said about him. He would remind Mr. Handley Page that his paper was not a question of patents, but simply a question of facts. Mr. Orville Wright had no interest now in the American patent, and the British patent expired in 1917. Langley made all his laboratory experiments with flat planes, as Mr. Handley Page said, and he apparently based his calculations on those flat surface experiments. His machine was built up and was a failure, and he recognised that it was a failure. Later on, eleven years afterwards, when interests with financial considerations came in, this historic relic, as Mr. Handley Page had said, was taken out of the Smithsonian Institution, where everyone respected it. It was cut into pieces; new wings were built, a new means for lateral control added, a different principle of trussing substituted, and, keeping most of these alterations in the background, it was reported to the Smithsonian Institution that this was the original machine. This new and changed machine was then put through trials to try to show that Langley's original machine would have succeeded if it had not met with an accident in launching, which "accident," he said, never occurred. It was the inevitable which took place—the collapse and fall of a machine which could not fly.

Referring to the letters received by the Secretary of the Royal Aeronautical Society from Dr. Walcott, Dr. Zahm, Mr. Manly and Mr. Curtiss, which arrived too late for reading at the lecture, Mr. Griffith Brewer says as follows:—

Replying generally to all four communications, I observe that they do not deny a single one of my statements of the changes made when building the Hammondsport machine, but merely dispute my conclusions. My statement that the Smithsonian Institution paid no more than the carriage of the machine to Hammondsport, however, appears to be contradicted. Dr. Walcott's statement at first glance would be taken to say that two thousand dollars had been paid to Curtiss out of the Langley Aerodynamical Laboratory funds. On a careful reading of his statement it will be found that he does not say this. Nor does Dr. Walcott, in his reply, specifically deny the truth of my statement. I instituted an inquiry at the Smithsonian Institution when I was in America and I based my statement in my paper upon the verbal assurance given by the Secretary's office that the Institution had paid only for the transport of the machine to Hammondsport; and also upon the statement of Mr. Orville Wright, who told me that Dr. Walcott himself had stated to him on the 21st of April of this year that the Smithsonian had paid only for the transportation of the machine to Hammondsport.

In reply to Dr. Walcott's criticism on my paper, I would first like to thank him for the kindly manner in which he has discussed my arguments. I have no doubt that Wilbur and Orville Wright fully appreciated the recognition of the

Smithsonian Institution when it conferred the award referred to by Dr. Walcott, for being the first to make actual flights in heavier-than-air power-propelled machines. When Dr. Walcott, however, states that he is not prepared to concede that the Wrights were the first to construct such a machine capable of such flight, he is, of course, referring to the Langley machine, which was not capable of flight in 1903. Moreover, when this "recognition" was made to which Dr. Walcott refers, he had evidently not then decided to reserve to the Smithsonian Institution the honour of having originated the first machine capable of sustained free flight. This claim was only put forward in later years after Mr. Langley's death, and is apparently solely based on what was done at Hammondsport. My paper refers to the actual doings at Hammondsport and the actual aerodynamic differences between the Hammondsport machine and the machine built by Mr. Langley, and I reiterate the case presented in my paper, that nothing done at Hammondsport has changed the situation. Langley designed and built a machine which failed to fly, and which anyone to-day with a knowledge of aerodynamics must know could not have flown. It makes no difference whether the Langley machine failed by breaking, or by want of balance, or because it bent out of shape so as to make it too inefficient to be flown, or from lack of propeller thrust. If it failed for any one of these causes, or for the combined failure of all of them, it would not be a machine capable of flight. In the Hammondsport machine all these and other faults were guarded against, and even then no sustained flights were made.

Dr. Walcott says that I appear to claim that the guying of the wings, the changes made in the engine, the changes made in the propellers, the changes made in the form of wings, and the changes in the rudder, were each indispensable on the Hammondsport machine. Dr. Walcott seems to forget that the Smithsonian report which he has circulated so widely, suggests that these changes were indispensable, because it refers to the Hammondsport machine as "the Langley aeroplane kept as nearly as possible in its original condition." Obviously, therefore, the changes made by Mr. Curtiss were indispensable, for the original condition was preserved wherever it was possible to avoid change.

As Dr. Walcott does not specifically deny a single one of the changes which I have enumerated in my paper, I think I am correctly giving the gist of his reply when I say that he expresses the belief, that because a machine with wings more roughly built and having a different camber, different area, different aspect ratio, different system of launching, different system of trussing, different weight, modified propellers, modified controls and with a modified motor had succeeded in getting off the water for approximately five seconds, therefore the original Langley machine of the original design and original construction *should* be able to fly.

Dr. Walcott seems to think it unfair that I quote Mr. Manly's statement made immediately after the tests of the original Langley machine as to the cause of the wreck, instead of a statement which he made in the Langley Memoir written some years afterward. However, the substance of this long quotation, which he gives from the Langley Memoir, is contained in the paragraph on page 624 of my paper, beginning with "After the machine had been recovered from the water," etc. I think that no impartial reader of my statement can say either that my quotation was garbled or that I have omitted any important matter stated in the long quotation reproduced in Dr. Walcott's reply.

Dr. Walcott at the end of his letter criticises the diagram in my paper showing the machine at Hammondsport. This diagram is a true representation of the Hammondsport machine as it was in the trials to which Dr. Zahm devotes the most space in his report. But since the machine was modified many times it would be impossible to represent it in this paper as it was in all the different stages.

The question of whether Dr. Walcott is prepared to concede that the Wrights were the first to construct a machine capable of sustained free flight does not concern the subject of my paper, because the decision on this point is not submitted to him for judgment. The claim of originating the first aeroplane capable of sustained free flight is put forward by Dr. Walcott after Mr. Langley's death as being due to his predecessor in the Smithsonian Institution, and he cannot pronounce judgment on this question and plead his claim at the same time.

Dr. Walcott touches the root of the argument when he claims these hops were "flights," because the official observer whom he appointed acknowledges that they were not really flights, because there was not sufficient propeller thrust. Flying may be compared to a person swimming. A person can either swim or he can't swim, and it is no use discussing how nearly he swims if he can't keep his head above water. An aeroplane can either fly or it can't fly, and it is no use discussing how nearly it flies if it has not enough propeller thrust to enable it to stay in the air as long as that amount of thrust lasts. The observer appointed by Dr. Walcott has stated that it was necessary to increase the propeller thrust. A Curtiss engine and a Curtiss propeller were therefore installed. The purpose of the propeller thrust was two-fold, *i.e.*, (1) to propel the Hammondsport machine on the water, and (2) to make it fly. We are all agreed that the machine had sufficient propeller thrust to propel it on the water, so it was not necessary to increase the power for this purpose. It was, however, according to Dr. Zahm, necessary to increase the propeller thrust, and to make the Hammondsport machine fly was the only other object. It is therefore obvious that the increased thrust, which Dr. Zahm says was necessary, was to secure sustained flight, which had not been attained. Even when the power was nearly doubled by substituting the Curtiss engine and modern propeller for the old Langley engine and twin propellers it could not make the machine fly, but only enabled it to leave the water when headed into the wind between the lulls and assisted intermittently by the gusts of wind.

In reply to Dr. Zahm, we all appreciate that unnecessary personalities, innuendos, and imputations of bad faith should be avoided so far as it is possible to avoid them, but nothing can be gained by indirect language.

It is in starting from an unsound hypothesis that Dr. Zahm arrives at erroneous conclusions. His simile of the eagle and the baby is inapplicable to the Langley machine, because the eagle had flown before losing its feathers. The bird he must choose to correct the simile is the ostrich. Even a scientist of the type referred to by Dr. Zahm cannot prove that an ostrich will fly by merely pulling out some of its feathers, loading it with misplaced weight, and then assuming that the handicap imposed warrants the assumption that it would have flown if the poor bird had been left alone to begin with.

Dr. Zahm now acknowledges a change of the aspect of the wings. He says, "True, the overall aspect ratio had been increased slightly; but what was the gain in efficiency—three or four per cent.?" Dr. Zahm further acknowledges that the "arched leading edge" was omitted at Hammondsport. A change in camber from one in twelve to one in eighteen made by these alterations improves an aeroplane surface of the Langley type by over twenty-five per cent. How can Dr. Zahm's acknowledgment now of these changes be reconciled with his statement that "the wings were identical in construction with the original machine, except, as I have heretofore stated, they were perhaps a little more roughly built and a little heavier."

Dr. Zahm now further acknowledges that the Hammondsport trials proved nothing as to the structural strength of the Langley machine. How does he reconcile his statement now with his previous statement in the Smithsonian Report which I have already quoted in my paper on page 630, in which he pretends that

the Langley trussing designed to carry 830 pounds carried 1,520 pounds actual weight in the later tests?

Dr. Zahm is aware that his statement is untrue, and when his attention is drawn to it he is silent. It would be idle to further discuss Dr. Zahm's statement while these glaring discrepancies exist between his statements and the facts.

Coming to Mr. Manly's lengthy statement, I approach this with some diffidence, because of my admiration for his courage in attempting to pilot the original Langley machine in 1903 at imminent risk of his life. For a man with no flying experience, such as the later pilots of the Hammondsport machine had acquired after the Wrights built the first man-carrying aeroplane, he was bold beyond conception, especially so when he knew that the machine he was to test had so small a chance to fly.

Mr. Manly reiterates the reasons on which he based his belief that the failure of the Langley machine in 1903 was due to an accident to the launching gear. My review of the same evidence I contend clearly proves that Langley failed because his machine was not capable of flight. It is for independent readers of the AERONAUTICAL JOURNAL to judge between us, and I venture to predict that the attempted flights of the Hammondsport machine in 1914 will not strengthen the claim of the Smithsonian Institution.

Mr. Glenn H. Curtiss is content to reiterate that the Langley flying machine of 1903 did fly in 1914 at Hammondsport "in its original condition with its original motor and propellers with no alterations except the addition of floats and their necessary supports." I was not content in my paper to merely deny this statement which Mr. Curtiss has made many times before, but I produced photographs and other proof to show that the Hammondsport machine was not the Langley machine with merely these differences, and I also submitted proof that even with this amount of changing the machine did not fly. Mr. Curtiss's flat contradiction of the photographs given in my paper carries no weight, especially as Dr. Walcott, Dr. Zahm and Mr. Manly acknowledge the changes and do not support him in this contradiction.

A member of the Society has suggested that my paper related to a purely commercial dispute on patent rights which could be more suitably raised in a Law Court. A Court of Justice could not be invoked by me to judge whether the disclosures in my paper are true or false. Only at the instance of Dr. Walcott, Dr. Zahm, or Mr. Curtiss could the truth of these disclosures be judged in a Court. My paper has nothing to do with any patent rights, nor to any commercial consideration. I had no financial interest to serve in writing my paper, and I have no connection, and never have had any, with the American Company which owns the American Wright patent.

To discuss the statements and conclusions given in such minute detail in these four letters would divert the issue from the real facts. The main purpose of my paper is to explode the fable that the Langley machine had been flown at Hammondsport. Neither Dr. Walcott, Dr. Zahm, nor Mr. Manly deny any of the changes pointed out in my paper. Mr. Curtis alone denies them, but he offers no proof to refute the photographs showing the changes he had made before the first trials. Dr. Walcott, Dr. Zahm, and Mr. Manly are content to contend that the changes were all made for some other purpose, which, far from helping the Hammondsport machine to fly, acted rather as a handicap. History does not want assumption and deductions. When a fact goes down to posterity, it must be based on something that has been done, and even those associated with the Smithsonian Institution cannot be credited with deeds accomplished merely because of their high scientific standing and their belief that these deeds could have been done. By all means let Dr. Walcott, Dr. Zahm and Mr. Manly believe that Langley's machine

would have flown if merely fitted with floats, handicapped with added weight, and with a skilled aviator in Mr. Manly's place. But they must stop there, and not say that the Langley machine has been flown, merely on the strength of their alleged belief that it could fly. No, the Langley machine is just where Langley left it—a beautifully executed delicate work suitable for a museum, but impossible in the air. It has never been flown and it never will fly.

[Editorial Note.—*Correspondence is invited on the above lecture and discussion.*]

THE MANŒUVRES OF GETTING OFF AND LANDING.*

Lecture delivered before the Society on November 3rd, 1921, by Squadron Leader R. M. Hill, M.C., A.F.C.

DISCUSSION.

Major-General Sir SEFTON BRANCKER said he knew Squadron-Leader Hill as one of our most daring, cool-headed and really scientific pilots. He had also realised that evening that he had a brilliant fund of imagination as well. His (Sir Sefton Brancker's) chief qualification for talking about getting off and landing was that he was once more notorious for making bad landings without hurting himself or anyone else than anyone in the Air Force. He was all for eliminating the human factor in control as time went on. He thought the devices which Major Hill had explained were absolutely on the right lines of progress. Pilots did not like the idea, but he was all for developing the stabilisers, height indicators, and all the gadgets that the Author had described. But there were limits to this policy. Some time ago there was an official objection from the French at Le Bourget that the British pilots were stunting. The stunt in question was the ordinary side-slip landing. He claimed that this was a perfectly legitimate manœuvre, and was probably the best form of landing; it should certainly not be counted as a stunt. From the commercial point of view, apart from safety, landings were of enormous importance, because heavily-loaded aircraft, if badly landed, received a serious shock throughout their structure which threw them out of truth and caused constant trouble, and extra labour, and more rapid deterioration, whereas with a good pilot who put them down very gently, they lasted longer, there was far less labour to be expended on keeping them in truth, and the depreciation involved was not nearly so great; so much so that he fancied the Oleo landing gear, or some equivalent, would have to come back for commercial machines; indeed, he thought that probably all the latest types had them. The speaker had mentioned one drawback to the Oleo gear in that part of his paper which he had not read that evening; it was not so good for getting off as the rigid type, which bumped a little and helped the machine into the air. The Oleo did not bump at all, and so full flying speed was necessary before one could lift the machine from the ground.

Captain BARNWELL said he had prepared a few notes on the written paper, but as they all referred to bits of the paper which had not been read, the ground was rather cut from under his feet. There was one point to which he would like to call the Author's attention :—He first of all told them that an aerodrome was the "pilot's paradise," and later in the lecture mentioned that the average aerodrome bumped a machine in taking off. The two statements hardly seemed compatible. He rather agreed with the latter description. It was impossible for him to talk with any authority about getting off or landing, because they were both parts of flying that needed a great deal of practice and observation before one felt competent to decide what one actually did and did not do, and in the very nature of things one gave the least possible practice to them, because they were the occasions most dangerous to the welfare of the aeroplane. He was strongly of opinion that more was to be gained by improvements in landing gears than by attempting, by some variable property of the wings, to reduce landing speed. His own feeling was that it was possibly easier to get into a field at, say, 100 miles an hour than at, say, 50, particularly if it were gusty and bumpy, and he thought one would come into the field at the 100 miles an hour quite

* See page 510.

happily if one had an under-carriage that would stand the greater vertical velocity (assuming vertical velocity as a function of horizontal) and had efficient braking devices which would stop the aeroplane safely in a short distance.

(*Communicated*): I cannot entirely agree with Major Hill that the proximity of the ground influences the pilot's handling of the aeroplane in taking off from an aerodrome. Personally, I believe that, almost directly after I have opened the engine "full out" (for taking off), I look practically at the horizon, and the distance the machine is above the ground does not consciously affect me.

Again, I am not certain that, in getting off, one finds any serious disadvantage in holding the machine on to ground up to a speed considerably above stalling, except perhaps for fear of breaking the propeller.

Regarding Major Hill's statement as to the behaviour of normal single-engined compared to that of normal twin-engined machines with respect to balance when "running up" engines on the ground, I imagine that slipstream effect on the tail plane should be as great for the normal twin as for the single, and am inclined to believe that the "nosing-over" tendency of the twin (noted by Major Hill) is almost entirely due to the lower chassis (relatively) of the twin.

Major Hill has not remarked that the "turning" tendency of the single-screwed aeroplane is due to the rotary motion of the slipstream; this "turning" tendency is of the sense noted by Major Hill, because the fin surface is mainly, or entirely, in the upper half of the slipstream; could one place the fin surface right on the centre of the slipstream there would be practically no "turning" tendency; could one place it mainly (or entirely) in the lower half of the slipstream the "turning" tendency would change in sign. In this connection one would very much like to know what "rudder" is necessary with the Parnall "Puffin," in which the fin is below the fuselage, and with, say, the latest Dornier flying boat, in which the airscrew axis appears to lie near the top of the fin.

Another point in connection with the "turning" tendency of single-screw aeroplanes :—The engine torque must tend to "bank" the machine, and a machine when "banked" tends to turn in the direction of the lowered wing tip if (as is usual) the "centre of pressure" on the total vertical fin surfaces lies aft of the C.B. It is probable that this "turning" tendency (due to torque) is very small, but it would be of interest to know of what order of magnitude it is compared to that due to slipstream on fins. It would also be very interesting to try whether, by placing suitable fin surfaces close behind the airscrew, one might not practically eradicate the rotary velocity of the slipstream and thereby eradicate any "turning" tendency.

A final point about "turning" tendency :—I have flown at least one machine of which I have gathered the impression that the "turning" tendency on the ground was of opposite sign to that in the air; that is to say, the machine (an R.H. tractor) tended to turn to the right taxi-ing, and to the left (*i.e.*, normally) in the air.

I have imagined that possibly "bending" of the slipstream, due to the ground surface, may account for the phenomenon; I should like to know if this "reversal" has been noted by anyone else, and if so, what is the reason for it.

I entirely agree with Major Hill that a low undercarriage, meaning only a small rake of the fuselage on the ground, is on the whole preferable for getting off, for taxi-ing, and for landing; the only disadvantage is the generally accompanying small angle of attack of the wings; but I feel quite certain that eventually we shall achieve ground brakes much more efficient and satisfactory than wing-drag. It should be noted that high wing clearance and high chassis, and (still more) small wing clearance and low chassis, are not necessarily synonymous.

Except for the possibility of damage to the wing itself, I am sure that the nearer the bottom wing is to the ground, the better for landing; but it would

appear that if a wing is higher than, say, one-half its own chord length above the ground surface there is little practical advantage from the proximity, so the larger the machine the more this advantage may be realised.

Major Hill mentions "bouncing" quite frequently. I feel sure that this is largely a temporary evil due to the somewhat primitive form of undercarriage from which it was impolitic to depart during the war; so although bouncing, with its accompanying effects on get-off and landing, is at present a serious consideration, it will not remain so much longer.

Major Hill would appear to include (and that necessarily) among the normal possible sources of danger in getting off and landing factors which might rightly be attributed to bad aerodynamic design. I grant that most, if not all, present-day aeroplanes are more or less badly designed; but it should not be long before we design machines without, say, appreciable yawing moment due to lateral control and without the possibility of any one control limiting seriously the power of any other.

I should like to corroborate, from unpleasant personal experience, the great difference between landing the average aeroplane (with a fairly high-powered stationary engine) throttled "right down" and "switched off" (or with the engine otherwise stopped). Such landings as most of us have the opportunity of practising are all "throttled," and I am perfectly certain that, to be as prepared as possible for a forced landing, the pilot must practise landing between marks, say, with his engine switched off.

I would also suggest that in the testing of a new design, landing switched off should always be included—it is quite possible that it might lead to modifications being found advisable.

I should like to express my personal indebtedness to Major Hill for the interest and instruction I have obtained by reading and thinking over his paper.

Wing-Commander CHRISTIE said the Paper had explained many phenomena which had hitherto been mysteries—to him, at any rate. Many heavy-handed pilots like himself with a great number of "write-offs" to their debit or credit would do well to digest the valuable tips the Author had given. He would limit himself to one or two points. The influence of wind on starting and landing manœuvres had been discussed, but, in addition, the changeable character of the atmosphere appeared to him to add to the pilot's difficulties considerably. It was his experience, and also that of others, that one had to land at a considerably greater speed in a warm damp temperature than in a dry air of the normal temperature to avoid stalling. Taking a high temperature as 30°C., or 84°F., and the air to be saturated with moisture, there was a decrease of approximately 7 per cent. on the specific density of the atmosphere as against the normal conditions at home at 10°C. That small advance did not seem to offer an adequate explanation. Could the increased amount of the water vapour in any other manner affect the lifting ability of the planes?

The Author's remarks on air brakes were interesting. It seemed probable that if an efficient air brake could be designed, its use in machines landing by night would be considerable, as it would permit a much steeper glide and lessen the danger of aircraft striking obstacles on the approach to the flare-path.

Regarding the Palethorpe tail-skid, how did this assist one to land in the dark? He knew remarkable landings were made by Captain Palethorpe at Andover, but he could not picture the functions of the tail-skid from the short description in the paper. The Noakes ground indicator seemed to be very much in the right direction, but did it punish a fast landing and could it be used on an aerodrome surface that was rough or uneven? Also was it effective in landing against strong winds? He suggested that the Author's organisation of an air port of the future was technically possible to-day, only the traffic and finances were lacking to support it.

Mr. Green said he was most interested in the landing gear question. He considered and he thought that Captain Barnwell would agree with him that under the stress of war conditions designers had provided bad landing gears, and it had only been due to the skill of the people using them that crashes were not more frequent than they have been. The Lecturer showed a picture of an aeroplane on its back, fitted with a landing gear which he (Mr. Green) had the privilege of designing, and of which he was now rather ashamed. It had been used during the testing of an automatic landing gear, and he (Mr. Green) felt confident that for the same weight and resistance as that landing gear a different gear could be now made which would have prevented the accident.

He thought that in the future improvement in landing gears would be made which would call for less skill on the part of the pilots.

The Author suggested that the Oleo gear was worse for getting off, but it seemed likely that the difference was so minute that another five revolutions of the engine would cover it. Squadron-Leader Hill thought that landing gears with greater shock absorption would be a great advantage. Landing gears had already been made of much the same weight as we formerly used, but with three times the shock absorption. It would not involve much weight to design landing gears to give six times the shock absorption, but it seemed hardly necessary to allow for more shock absorption than was sufficient to absorb shock of landing at the normal gliding angle of the machine.

There was one manœuvre on landing which on most machines was impossible. When one reached the ground one frequently wanted to stop quickly. This could be done by brakes or by swinging the machine round quickly. It was the latter manœuvre which could not be done on the average aeroplane to-day as one got a wing tip in the ground and turned over. Landing gears could be made which would admit of rapid turning on the ground, and he did not think that the increase of weight would be serious. Of course, the landing gear would need to be made of wider track and stronger sideways. Looking into the future, he thought they would see aeroplanes landing fairly fast and swinging round in a very small circle. With a hydraulic landing gear one might even turn at high speed on the ground by causing the Oleo leg to bank the machine in such a way that the wings could take the lateral force and stop the aeroplane skidding sideways.

Wing-Commander Bowen said so far as his own landings and getting off were concerned, they made him think the age of miracles was not yet past. He was interested chiefly now in the instrument side, and one felt that there were extraordinary difficulties in the instrument side. The branch of research which he was in had been trying proximeters, *i.e.*, electrical devices for telling a pilot when he was getting near the ground, and so on. They realised the enormous difficulty of it, but had not done much else. He thought there must be some mechanical solution of the problem. The two they had seen that evening seemed very helpful. Wing-Commander Christie made an interesting point about landing in mists. In the East landing was complicated by higher landing speeds. Had the Author anything to say on how to compete with conditions in some parts of the East where the ground wind might be ten miles an hour and boxing the compass in three minutes or less?

Captain G. T. R. Hill said it was nine years ago that day since his brother and he put a full-sized glider into the air. That was, he thought, the beginning of the Lecturer's active study of getting off and landing, and of the effect on the structure of the machine of contact with the ground. Since that time the Lecturer had made a large number of landings, some good, some bad, and he thought that the results, analysed and collected as they had been, formed a valuable contribution to the knowledge of all, particularly those who were not pilots themselves.

To give an example, the other day a so-called deck-landing expert gave forth as his considered view that aeroplanes for deck landing were all right and the

ships on whose decks landings were to be made were all right, but all that was required to achieve greater success was more confidence on the part of the pilots. He thought he was absolutely wrong. The aeroplanes were wrong and the ships were wrong. That did not mean that they were not good, but that they might be better. He was not prepared to throw the whole blame of any lack of success there might be on the pilots. He hoped this paper would enlighten those who did not fly on the difficulties and trials the pilots had to face. On the other hand, after a long experience of flying it was difficult to put oneself in the place of someone learning and feel again the old difficulties and trials.

A technical point upon which he would like opinions was the minimum clearance necessary between the lower plane and the ground. It was generally agreed that it was easier to land with the lower wing close to the ground. On the Vickers-Vimy which had been shown, the bottom plane was about 3ft. from the ground, and the same figure held roughly for the little Bristol. On the large aeroplane that distance, relative to the chord of the wing, was much less. It would be interesting to have various pilots' opinions as to whether the plane should be placed a certain absolute distance from the ground regardless of the size of the aeroplanes, or whether it should depend on the span or chord of the wing. On the one hand it might be argued that machines have to land on the same sort of aerodrome, and the minimum height necessary should be considered to be that which would just clear small bushes or obstacles, but on the other hand, when landing with a small amount of bank the height of the lower wing must depend to a certain extent on the span of the aeroplane if the wing were not to touch the ground.

Captain Barnwell's statement about landing at 100 miles an hour sounded rather dangerous, and he thought the insurance companies would take that view. It was all very well to excuse these high landing speeds by good undercarriages, but one wanted a comparatively slow landing and a good undercarriage too.

He would confess to being responsible for one of the crashes shown on the screen; the picture was, however, used to illustrate the correct way of crashing without hurting oneself. He hoped any pilot who found himself just about to crash would not review his past life in that last moment, which he is usually supposed to do, but would remember the picture which had been shown and crash in the correct manner.

In reference to a question by Mr. McKinnon Wood as to how he did it, Captain Hill said it was difficult to give a very clear account of what happened. The main idea was to put one wing down so that, being below the level of the undercarriage, it would touch the ground first. He did not think that there was anything in bringing a wing forward by using the rudder.

Mr. McKinnon Wood said he could not speak as an expert as he had never done any of these manœuvres. He was interested to know on what lines research and design ought to be developed. He also was surprised to hear Captain Barnwell say landings should be made in the future at 100 miles an hour. He had always understood low landing speeds were desirable, and he felt that was so, coupled with a very improved undercarriage. The subject of landing had been neglected, because we had passed through a war period when one was forced and prepared to take much greater risks. He thought it would be agreed that there were much too many crashes in landing. The high landing speed might be all right in a good aerodrome, which might have larger dimensions than at present; but even if effective brakes were provided the pilot would not be in a happy position when he had to execute a forced landing.

Flight-Lieutenant Noakes, who was responsible for the ground indicator and who was asked by the Chairman to answer Wing-Commander Christie's questions, said it was purely an idea for landing at night or in fog. The device had a Vernier adjustment. If one came in to land at 60 m.p.h. the pull required on the

control column was more than required if landing at 70 m.p.h. There were oscillations when approaching the ground fast. The ground indicator worked just the same in a high wind. The ground indicator was attached to the control column by a wire and shock absorber so that the pilot could overcome all the pull which was exerted on the control column by the indicator arm being on the ground. For each type of machine the correct pull required on the control column would have to be found out by a series of flights.

Squadron-Leader Hill, replying to the remainder of the discussion, apologised for not alluding to the paper in greater detail. He had been afraid of taking up the time unduly, so he had tried to convey the spirit of the paper rather than parts of the letter. The point referred to by Sir Sefton Brancker, of what were called stunt landings, was certainly a vexed one. The sideslip landing was hardly a stunt, it was a gentle gliding manœuvre; in fact, to those who were not accustomed to watching aeroplanes fly, it would hardly be apparent that the aeroplane was doing a sideslip landing. One would notice that it was canted over on the glide down, but not that any violent contortions or evolutions were being carried out. The point about consistently good landings was an interesting one. If any aeroplane were consistently badly landed one found, after a bit, that the various fittings crushed into the wood a little—enough to make one feel unhappy—and trouble of that sort made the effective life of the aeroplane much shorter than it should be. He must yield to Captain Barnwell the point that his (the Author's) remark about an aerodrome being a pilot's paradise was inconsistent with the later statement about the bumps. He thought that improvement in undercarriages was wanted, that reduction of landing speed was wanted, and that these, combined with the extra confidence that pilots would thereby get, would make civil aviation a really sound proposition. In regard to Wing-Commander Christie's remarks on the influence of wind, it was an observed fact that if one landed in a strong wind one felt the aeroplane dropping unexpectedly. The question as to what happened in a warm damp temperature he would like to leave to someone more competent to answer. He had not observed very much there. Anything new that was observed would be very valuable, and that was what one hoped would come out in a discussion of that sort. He would not like to say anything about moisture. The effect of heat in the East they did, of course, know about, and, apart from the height of some aerodromes which increased the landing speed of aeroplanes, there did seem to be an effect due to the temperature itself. Wing-Commander Christie's other questions, he thought, had been answered by Flight-Lieutenant Noakes. The use of the ground indicator, as Flight-Lieutenant Noakes described it, was perfectly possible on the S.E. 5A. If one decided to glide down at 70 m.p.h., one could glide down to the ground with one's head near to but not actually touching the control stick. When the ground indicator touched the ground it flattened the aeroplane out. If every time the aeroplane was flattened out in this way one just put the control stick forward again, one could go on undulating a few feet from the ground allowing the indicator to keep on touching it. Every time the indicator touched the ground the control stick would come back. With a little improvement the ground indicator would give the pilot all the confidence that was necessary. He was interested in Wing-Commander Bowen's statements as to the instruments he had been trying. Something was wanted to convey to the pilot vividly the fact that he was meeting the ground. He was like a man waiting for a bull to charge him and he was not going to look at small indications of needles or anything like that.

He (the Author) knew that Major Green had made an Oleo undercarriage for a scout which weighed no more than an ordinary elastic sprung scout undercarriage. That, he considered, was a real achievement. The Oleo undercarriage would have to come. A wide track would be necessary, whether it was a question of allowing one to swing round quickly without tipping over or simply to steady the aeroplane when making contact with the ground. Undoubtedly, improve-

ments would come. They would, he thought, come rapidly; and, as a commercial vehicle, they need not have any fear about the ultimate perfection of the aeroplane.

Wing-Commander Christie desired to know more precisely the function of the Palethorpe tail skid, especially in its capacity to assist landings made at night. Captain Palethorpe's idea was to glide down to the ground at a flat angle by using a certain amount of engine. When he thought he was a few feet off the ground he partially flattened out, but did not, as in the normal way, carry out the whole flattening out operation. The wheels would then strike the ground, perhaps rather hard, so that in the normal way the aeroplane would have bounced off the ground violently. As soon, however, as the aeroplane started to bounce the nose would go up and the tail come down, thus bringing the long tail skid into contact with the ground. The tail skid would absorb the shock by means of its Oleo. but at the same time stop the nose of the aeroplane going up further so that it would drop. The wheels would again touch the ground and bounce less violently. In practice this bouncing was damped by the Oleo tail skid almost at once. The net effect was to allow the pilot to flatten out only partially, instead of having to carry the flattening out operation to its conclusion, which is a more difficult thing to do correctly at night, and involves the risk of stalling too high above the ground.

Wing-Commander Bowen asked what the Author had to say about landing in the East when the wind boxes the compass in three minutes. If the wind changes so rapidly it may be practically impossible to land into it. The pilot is then forced to land across it. He must, therefore, be provided with improved undercarriages. This is where the wide track undercarriage will undoubtedly be of enormous value to him.

The Chairman, in moving a vote of thanks to the Author, said no doubt the moments of getting off and alighting were the moments of compulsory skilfulness in flying, and any instrumental assistance at that critical time might eventually be of service. He thought it was very interesting to hear the change of attitude that existed in this year of grace, compared to what it was eight or nine years ago or early in the war, when the attitude of many pilots towards any device that did what the pilot did previously was disliked, much as the workman disliked the spinning jenny because it was doing his job. Various devices were made, such as the now universal speed indicator, and the opposition to the scientific side really was, in his opinion and he thought in that of many others, a brake on the progress of aeronautics—a brake now happily removed. Such devices as had been described would build up the future of civil aviation and such a lecture as Squadron-Leader Hill's advanced the cause. It was an advantage to the Society to have Squadron-Leader Hill as lecturer, and it was also pleasant to know that the Research Committee had considered the Royal Aëronautical Society a good mouthpiece—which he thought it undoubtedly was—for approaching the public, the flyers, and designers for a discussion on this subject.

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